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Edited by
Professor Nicholas Polunin

ONIONS AND THEIR ALLIES

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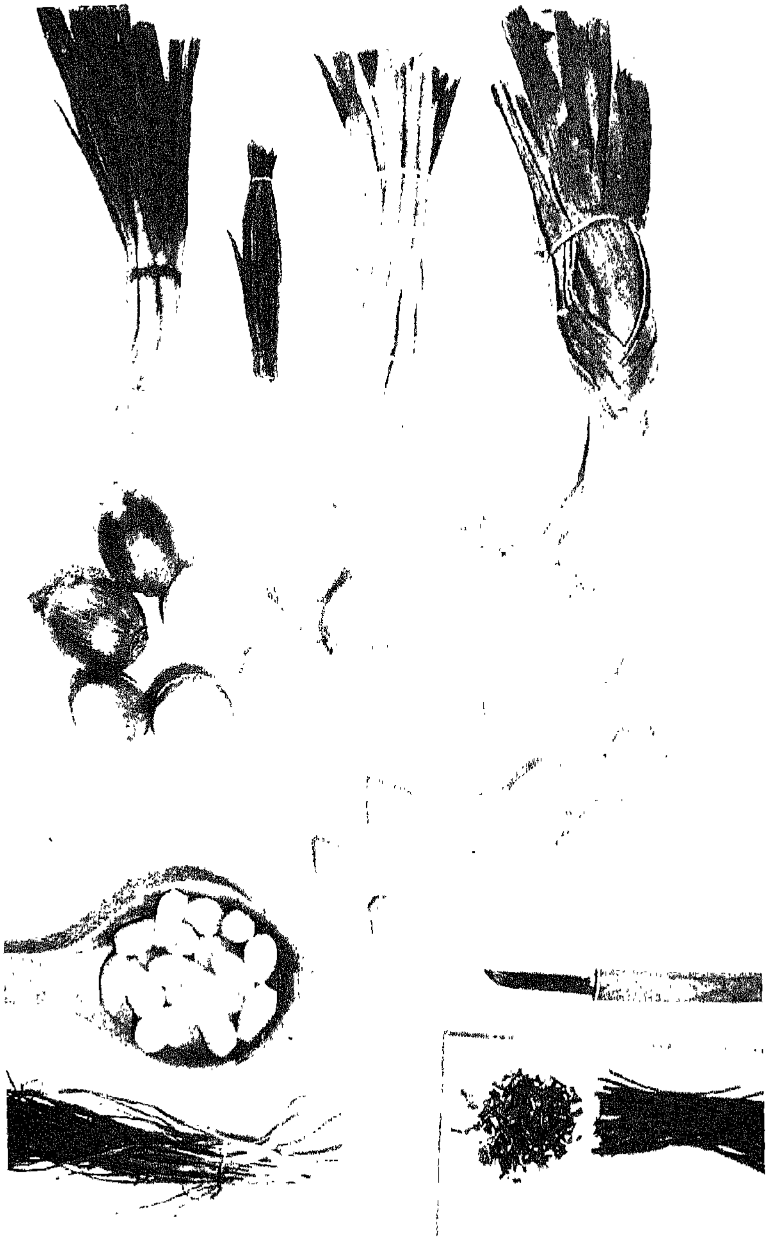

Photo M. P. Mann

The Alliums most commonly grown for food. At top, left to right, are bunches of the common onion, Chinese chives, the Japanese bunching onion, and leeks. Mature bulbs of the common onion appear at left-centre. Above the knife are common garlic (*right*) and three cloves of great-headed garlic (*left*). At the lower left are pickled bulbs and fresh plants of rakkyo; at the lower right are common chives. (Knife blade = 8 cm.)

PLATE I

WORLD CROPS BOOKS
Edited by
PROFESSOR NICHOLAS POLUNIN

ONIONS
AND THEIR ALLIES

Botany, Cultivation, and Utilization

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herbicides. Moreover, new herbicides are constantly being added to the long list already in existence. Here again it is advantageous to call upon specialists who are working actively in this particular field of endeavour.

We have avoided almost entirely a discussion of machinery and equipment, and of the construction of storage houses, etc., as we have considered such matters to lie outside the domain of this book.

Statistics on world production and on exports and imports have been obtained chiefly from reports of the Food and Agriculture Organization of the United Nations. These statistics do not always agree with those obtained from individual countries and, as we have not attempted to alter figures to make them coincide, some inconsistencies may be found.

We have received information from many sources and from many individuals. None the less, we know that our presentation on certain topics is far from complete. We shall sincerely appreciate having our attention called to any errors or omissions, and meanwhile emphasize that, within the orbit prescribed by the Editor, Prof. N. Polunin, we alone are responsible for the choice of subject matter and for its emphasis in the various chapters.

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H. A. J.
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I

WORLD PRODUCTION

THE demand for onions is world-wide. Their use is not limited to any climate or associated with any nationality, and they are probably as widely grown as any cultivated crop. Onions are found on most markets of the world at all seasons of the year. Although they are consumed in rather small quantities by most families, they are used in many homes almost daily—primarily as a seasoning for a wide variety of dishes. Onions are consumed in about the same amounts when the prices are high as when they are low, i.e. the demand for onions is fairly constant. Despite the fact that it is possible to predict rather closely the amount of onions that any market will absorb, it seems almost impossible so to regulate the flow of onions into marketing channels that the consumer can always purchase onions at a reasonable price and the grower can make a reasonable profit. A year of over-production and low prices is usually followed by a year of under-production and high prices.

In this chapter we are concerned primarily with the production of mature bulbs of *Allium cepa*, with the areas in which they are produced, and with their movement into world markets. Unfortunately, statistics are not available from some of the countries that are known to grow the crop extensively. Table I indicates the production in hectares and tonnes (metric) for the countries that are most prominent in onion growing. The leading onion-producing countries, in order of importance, are the United States, Japan, Spain, Egypt, Turkey, and Italy. The yield per hectare can be calculated from the data presented. Turkey has more land in onions than the United States, but the yields are lower, while the Netherlands leads in yield per hectare.

The long list of importing countries in Table II shows that the onion is an important item in world trade. In many lands, onion bulbs are harvested over a short season, and for the remainder of the year must be supplied from imports or from storage. For example, mild-type spring onions move from Italy into northern European markets early in the year, because new-crop mild onions are usually in demand even when there is an abundant supply of more pungent stored onions. Highly industrialized nations, such as the United Kingdom and West Germany, are leading importers of onions (Table II). Ceylon, Canada, and the Federation of Malaya-Singapore, are also heavy importers, with an average of about 42, 37, and 35 thousand tonnes per annum, respectively, for the years 1954–58.

TABLE I

ONION PRODUCTION BY COUNTRIES, 1955–56 TO 1959–60

(Production Yearbook, F.A.O., v. 12–14 (1958–60) 1959–61)

Country	Hectares (thousands)					Tonnes (metric, thousands)				
	1955–56	1956–57	1957–58	1958–59	1959–60	1955–56	1956–57	1957–58	1958–	1959–60
Algeria	...	6	6	5	5	...	72	72	68	83
Argentina	9	10	9	10	11	155	182	178	178	156
Australia	3	4	5	4	...	40	55	73	56	...
Austria	1	1	1	1	1	14	16	17	16	15
Brazil	32	37	37	39	38	155	200	179	180	191
Canada	2	2	2	3	3	53	45	51	52	65
Ceylon	7	7	6	5	6	45	41	50	33	39
Chile	3	...	4	4	5	105	105	120	92	129
China, Taiwan	3	3	3	4	4	25	25	26	34	31
Czechoslovakia	5	4	5	5	5	57	44	46	57	70
Ecuador	...	6	5	5	6	...	71	65	69	85
Egypt	48	48	56	58	66	415	403	481	462	558
France	10	11	11	11	12	165	186	154	169	176
Germany, East	4	4	...	4	4	48	50	...	...	...
,, , West	2	1	1	1	1	32	24	24	25	17
Greece	11	11	11	10	11	137	130	139	133	130
Hungary	6	6	7	5	8	77	53	80	40	...
Israel	3	2	2	2	2	23	21	19	24	23
Italy	24	23	25	27	28	252	241	278	334	346
Japan	43	51	46	47	50	731	881	768	825	933
Korea, South	2	3	3	2	3	24	32	32	31	39
Lebanon	2	2	2	2	2	30	37	35	36	33
Mexico	14	16	16	16	16	56	62	62	64	65
Netherlands	5	6	6	7	6	131	155	175	212	162
Pakistan	...	19	19	23	23	...	133	133	146	146
Poland	17	17	17	19	20	162	141	151	183	197
Romania	31	27	29	31	33	217	125	170	148	267
Spain	28	29	29	34	34	537	576	585	718	735
Syria	4	4	3	3	4	25	31	35	32	28
Turkey	48	56	65	51	56	300	358	464	405	424
United Kingdom	3	3	2	2	2	43	58	49	42	34
United States	46	50	45	43	46	971	1109	1101	1077	1159
Yugoslavia	23	21	23	23	27	143	103	161	108	190

... = no figures available.

TABLE II

IMPORTS OF ONIONS BY COUNTRIES, 1954–59

(Trade Yearbook, F.A.O., v. 11 Part 2 (1957) 1958; v. 13 (1959) 1960; v. 14 (1960) 1961)

Country	Tonnes (metric, thousands)					
	1954	1955	1956	1957	1958	1959
Austria	5·8	11·9	15·6	10·7	9·8	11·0
Belgium-Luxemburg	11·1	13·9	12·8	10·8	10·9	18·0
Canada	31·0	37·8	38·0	39·4	36·9	37·8
Ceylon	44·5	37·6	37·0	38·1	51·0	63·1
Cuba	32·8	33·6	23·1	25·0	26·1	35·8
Czechoslovakia	—	...	9·0	12·9	9·4	12·6
Denmark	2·5	5·3	5·6	2·6	2·6	4·8
El Salvador	—	0·7	4·0	5·0	5·3	6·6
Finland	2·0	3·2	3·1	1·6	2·2	2·1
France	9·1	21·2	26·9	13·9	32·7	44·6
'French' West Africa	5·3	5·3	5·1	5·5	...	...
Germany, West	68·4	109·0	138·4	142·0	133·0	133·7
Iraq	1·4	2·1	0·6	5·5	4·2	1·8
Ireland	6·3	8·3	5·9	4·2	3·9	3·7
Jordan	3·3	5·6	3·5	7·0	5·7	5·2
Lebanon	1·5	1·4	1·6	7·0	2·8	2·6
Malaya–Singapore, Federation of	33·6	37·0	35·5	33·4	34·2	35·5
Mexico	1·3	—	0·2	3·2	0·9	5·5
Netherlands	7·1	17·2	11·4	9·4	7·2	15·5
Norway	4·2	5·4	3·7	4·6	4·1	4·5
Panama	2·4	2·5	2·6	3·2	3·2	3·4
Philippines	3·3	2·8	4·3	1·5	0·9	—
Sierra Leone	1·6	2·3	2·4	2·9	4·0	4·5
Sweden	8·5	10·7	9·3	9·1	10·8	11·5
Switzerland	8·6	8·9	11·2	10·4	8·6	7·6
Thailand	—	2·5	3·3	3·0	2·8	2·4
United Kingdom	217·4	224·2	218·7	223·5	229·9	224·0
United States	6·8	9·5	12·0	12·2	24·8	26·8
West Indies Federation	5·5	7·7	6·3	6·6	7·5	7·6

... = no figures available.
— = none or negligible.

Egypt leads in onion exports, followed in order by the Netherlands, Spain, the United States, and Italy, while India, Lebanon, Chile, Hungary, the Republic of South Africa, Syria, and other nations, move considerable quantities of onions into world markets (Table III). Several species of *Allium* are used rather extensively in China. However, we know very little about the economic importance of *A. cepa* there, and for many Asian countries onion statistics are not available. Even for countries for which statistics are available, it will be noted that the United Nations data (Tables I, II, and III) may vary widely from figures we have secured from other sources.

TABLE III

EXPORTS OF ONIONS BY COUNTRIES, 1954–59

(Trade Yearbook, F.A.O., v. 11 Part 2 (1957) 1958; v. 13 (1959) 1960; v. 14 (1960) 1961)

Country	Tonnes (metric, thousands)					
	1954	1955	1956	1957	1958	1959
Algeria	2·1	4·0	3·7	6·9	1·3	0·2
Argentina	—	—	1·0	7·3	5·4	4·6
Australia	3·7	2·1	1·0	3·0	5·7	2·0
Bulgaria	...	16·0	6·1	7·6	5·3	14·0
Canada	2·5	3·2	2·6	4·0	2·8	3·3
Chile	8·6	16·4	17·3	16·0	33·9	25·2
Cyprus	5·0	3·2	1·0	0·1	—	1·0
Egypt	169·5	173·1	195·0	156·4	169·6	178·6
France	12·6	7·9	6·1	7·6	6·9	11·9
Hungary	15·2	—	56·5	18·2	15·3	29·1
India	28·1	30·0	39·8	36·9	68·2	78·5
Iran	3·6	3·8	6·2	6·3	5·5	5·6
Italy	29·3	53·0	71·2	69·2	65·0	78·0
Japan	10·9	5·4	13·4	5·2	8·7	9·8
Lebanon	28·7	35·3	21·9	21·8	21·6	18·2
Malaya–Singapore, Federation of	8·5	8·9	7·4	6·1	8·4	4·7
Mexico	6·5	—	8·1	7·3	12·8	5·7
Morocco, former French Zone	2·7	2·1	2·5	7·8	9·0	4·7
Netherlands	91·2	109·2	123·1	138·8	165·6	135·8
New Zealand	1·0	3·0	3·0	1·4	2·0	3·1
Poland	3·7	9·0	3·3	5·9	8·7	41·1
Portugal	2·8	2·6	3·2	5·0	3·7	3·5
Republic of South Africa	7·3	5·1	10·9	10·2	6·0	10·8
Spain and Canary Isles	79·8	85·5	84·7	83·6	77·5	71·0
Syria	14·9	10·4	6·5	5·0	7·1	5·8
Thailand	2·2	4·8	2·8	1·0	1·3	1·5
United States	62·7	72·3	79·8	77·3	62·5	65·6
Yugoslavia	8·6	5·9	0·8	—	0·8	1·4

... = no figures available.
— = none or negligible.

THE AMERICAS

Onions are grown from Canada and Alaska to the southern extremity of South America. Brazil, Canada, Chile, Mexico, and the United States, grow large quantities for home consumption. Chile exports about 20 per cent of her crop, Mexico about 10 per cent, and the United States and Canada about 6 per cent. Almost all American countries import some onions, Cuban imports being especially large.

UNITED STATES

In the United States, onions rank high in value among vegetable crops. They are being harvested somewhere in the United States from late February to late October in each year; but although they are grown in every state, production of onions is concentrated in certain districts.

Early onions—mostly mild types such as 'Early Grano', 'Granex', and 'Bermuda'—are grown in the Southwest, Texas being the leading state, with New Mexico, Arizona, and California, all producing considerable quantities. Onions from these states are shipped by truck and rail to markets in the northern United States and Canada from March through June.

Large, mild, sweet Spanish-type onions are grown on the irrigated mineral soils of the western United States, chiefly in Colorado, Idaho, and Oregon. These are marketed from the field in summer, and out of storage from October to January. Hard-fleshed, long-keeping, pungent yellow globe onions are grown as a direct-seeded crop in the muck soils of the northern and western states of New York, Michigan, Ohio, Indiana, Wisconsin, Minnesota, Oregon, and California. These move to market from field and storage from September to April.

During the early summer, domestic markets are supplied with onions that have been produced from dry sets which were planted as a spring crop in the north, and also with large mild onions that have been grown as a winter crop in central California. At this time of year, home garden supplies are also abundant.

In the State of Hawaii, about 340 tonnes of onions are produced annually, but another 2,500 tonnes are shipped in, mostly from the mainland. Onions at present are grown chiefly in the Kula and Kihei farming districts on the island of Maui. The short-day, F_1 hybrid 'Granex' is the best-adapted onion for Hawaiian conditions (Nakagawa, 1957). Onion growing in Alaska is somewhat limited, chiefly by the short growing-season. Some mature bulbs are grown from imported dry sets, and a few from transplants; but, when in season, green salad onions from direct seeding provide the chief source of supply (Prof. C. H. Dearborn, personal correspondence).

The United States imports annually considerable quantities of onions from Mexico, Italy, Chile, Egypt, and Spain (Table IV). White onions are obtained from the Tampico district of Mexico, chiefly during the late winter and early spring. Imports from this district are fairly constant from year to year, as it is about the only source of white onions at this season. When the early crop is short in the United States, imports are increased from Chile and Egypt. The dark-red, extremely mild types from Italy are always in moderate demand—especially in the large eastern markets.

Onion exports from the United States greatly exceed imports. Although these exports go to about forty different countries, 75 per cent have been to Cuba and Canada (Table V). The 'Australian Brown' onion from central California, and the 'Red Creole' from southern Louisiana, provided most of the export to Cuba. During the years

TABLE IV

UNITED STATES IMPORTS OF ONIONS, BY COUNTRY OF ORIGIN, 1954–59

(U.S. Dept. Agric., For. Agric. Ser., For. Agric. Trade of the U.S.)

Country of origin	Tonnes (metric, thousands)				
	1954–55	1955–56	1956–57	1957–58	1958–59
Chile	1·5	0·8	1·9	6·8	11·6
Mexico	4·3	7·5	7·4	15·4	5·6
Italy	2·5	2·7	3·0	4·2	3·1
Egypt	—	—	0·2	0·1	3·1
Spain	0·1	0·0	0·1	0·0	0·0
Other countries	0·0	0·0	0·0	0·2	1·6
Total imports		11·0	12·7	26·7	25·0

0·0 = less than 100 tonnes.
— = no data available.

TABLE V

UNITED STATES EXPORTS OF ONIONS, BY COUNTRY OF DESTINATION, 1955–59

(U.S. Dept. of Commerce)

Country of destination	Tonnes (metric, thousands)					Averages—1955–59	
	1955	1956	1957	1958	1959	tonnes	Per cent
Canada	29·6	29·0	29·8	26·9	24·2	27·9	39·1
Cuba	28·1	27·0	28·9	22·7	27·9	26·9	37·7
Mexico	3·8	1·8	4·6	4·6	5·4	4·0	5·6
Jamaica	2·0	1·9	2·4	2·5	1·8	2·1	3·0
Panama	1·8	2·1	2·3	1·6	1·8	1·9	2·7
Philippine Republic	0·8	3·8	2·3	—	—	1·4	1·9
Dominican Republic	1·3	1·8	1·1	1·4	1·0	1·3	1·8
Germany (West)	—	3·5	1·9	—	—	1·1	1·5
Netherlands	—	4·1	0·4	—	—	0·9	1·3
Trinidad	1·1	0·9	1·0	0·6	0·4	0·8	1·1
Other countries	3·6	3·9	2·6	2·0	2·9	3·0	4·2
Total	72·2	79·7	77·2	62·3	65·4	71·4	

— = no data available.

1954–58, about 6 per cent of the total United States crop was exported. Imports are very small (1·5 per cent) in relation to domestic production.

CANADA

The annual onion production of Canada for the years 1954–58 was about 50,000 tonnes (Table I). During the same years Canada's annual imports were about 37,000 tonnes. Most of these came from the United States; other important sources were Chile, Egypt, and Spain. Exports amounted to about 3,000 metric tonnes annually. The two main onion-producing provinces of Canada are Ontario and Quebec. Ontario grows more onions than all of the other provinces combined; the most important district in this connection is Bradford Marsh, where, in some years, more than a million bushels of direct-seeded onions are produced. These are mostly hard-fleshed, yellow globe-type onions that keep well in storage. Onions are harvested in Canada from June to October, but the main harvesting season for the late-storage crop is September and October.

MEXICO

The two most important onion-producing districts in Mexico are the eastern coastal plain near Tampico and the high plateau in the vicinity of Celaya. Mexico produces white onions almost entirely. Those from around Tampico supply domestic markets and considerable quantities for export; those from Celaya are sold in Mexico City, Guadalajara, and other domestic markets. The Tampico onions are harvested chiefly during the winter and early spring; in the Celaya district, planting and harvesting are continuous operations throughout the year.

CENTRAL AMERICA

The Central American countries of Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama, grow only a few onions in the high altitudes, so that all must import onions from the United States and other countries.

SOUTH AMERICA

In South America, Brazil, Argentina, and Chile rank first, second, and third, respectively, in onion production. During the years 1955–58, Brazil produced an average of 178,000 metric tonnes annually and Argentina 173,000 tonnes. For neither of these countries is the onion important in international trade.

Between 1955 and 1958, onion production in Chile averaged 105,000 tonnes per annum. Chilean onions are harvested from November to April, but chiefly in February. From 16,000 to 18,000 tonnes are exported annually (though the usual figure was practically doubled in 1958), mostly during March, April, and May. Canada, the United Kingdom, and the United States, take a considerable portion of the Chilean exports, which compete in world markets chiefly with the crop from Egypt. Onions from Chile are carefully graded and packed, and are well received on world markets.

AFRICA

Ancient and modern records provide a wealth of information about the economic importance, culture, and uses, of the onion in Egypt. Onions are grown to some extent also in the Republic of South Africa, Morocco, and Algeria,[1] but for other African countries information is rather meagre.

EGYPT

Egypt has long been famed for its onion industry. It ranks fourth among the countries of the world in the total amount of onions grown, being surpassed only by the United States, Japan, and Spain (Table I), but it stands first among nations in onion exports (Fig. 1). The onions are grown as an early summer crop in the delta region, where they are usually interplanted with cotton, and as a winter crop in Middle (Cairo to Asyut) and Upper Egypt (Asyut to Aswan), chiefly in the provinces of Beni Suef, Minya, Sohag, and Asyut. The summer crop of the delta is mostly the cultivar Behairy; the winter crop is mostly Sahidy or Giza No. 6, a selection out of Sahidy. The winter crop is the one that is chiefly used for export. Egyptian onions are pungent and very firm and, when cured properly, keep well. They can be handled rather roughly without injury, and can be shipped long distances under unfavourable conditions. Onions are Egypt's second most valuable export crop, being exceeded only by cotton. Over 70 per cent of the exports are usually sent out in March, April, and May. For decades the United Kingdom received more of the Egyptian crop than any other country, but during

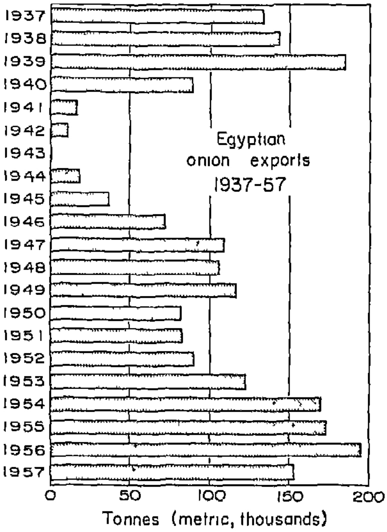

FIG. 1.—Egyptian exports of onions, 1937–57. Egypt stands first among nations in onion exports, and among her export crops only cotton exceeds onions in value. In onion production Egypt ranks fourth among the nations of the world.

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[1] Also in Nigeria, at least for local consumption.—*Ed.*

TABLE VI

EGYPTIAN EXPORTS OF ONIONS, BY COUNTRY OF DESTINATION, 1954–59

(W. A. Warid, University of Cairo)

Country of destination	Tonnes (metric, thousands)				Averages—1954–57	
	1954	1955	1956	1957	tonnes	Per cent
United Kingdom	58·0	52·0	50·2	5·7	41·5	24·0
Germany, West	37·6	34·6	44·6	27·9	36·2	21·0
Netherlands	5·0	10·0	12·7	30·4	14·5	8·4
Malaya, British	21·5	18·2	10·7	2·2	13·1	7·6
France	7·5	15·4	16·8	—	9·9	5·8
Indo-China	3·7	5·3	2·6	23·2	8·7	5·0
Switzerland	2·8	3·8	4·4	11·0	5·5	3·2
Belgium–Luxemburg	4·6	4·6	5·1	6·3	5·2	3·0
Ceylon	6·1	1·1	1·5	9·9	4·6	2·7
Austria	1·8	1·5	9·5	3·5	4·1	2·4
Saudi Arabia	1·9	3·0	3·6	6·5	3·8	2·2
Denmark	1·9	2·5	3·4	6·7	3·6	2·1
Sweden	2·9	4·3	3·8	3·3	3·6	2·1
Br. E. Eq. Africa	2·1	2·5	3·2	1·3	2·3	1·3
Germany, East	—	—	—	7·3	1·8	1·1
Czechoslovakia	0·0	—	3·4	3·9	1·8	1·1
Finland	0·5	0·9	1·4	1·1	1·0	0·6
Norway	1·4	1·6	0·6	—	0·9	0·5
Canada	0·9	1·1	1·1	—	0·8	0·4
Italy	0·2	0·3	2·6	0·0	0·8	0·4
Ireland (Republic)	0·5	0·4	—	—	0·2	0·1
Indonesia	0·3	0·3	—	—	0·1	0·1
Australia	—	0·4	—	—	0·1	0·1
United States	0·0	0·0	—	—	0·0	0·0
Other countries	8·2	9·5	13·6	2·5	8·5	4·9
Total	169·6	173·1	195·0	152·6	172·6	100·0

0·0 = less than 100 tonnes.
— = no data available.

the years of World War II the volume dropped considerably, and it took another dip in 1957. Egyptian onions are shipped all over the world, but European countries are in general the chief recipients (Table VI).

REPUBLIC OF SOUTH AFRICA

Cape Province is the most important onion-producing province in the Republic of South Africa, followed by the Transvaal, Orange Free State, and Natal. In the Transvaal, only early-maturing onions, such as 'Texas Early Grano' and 'Early Cape Flat', are grown. These are moved to market as soon as they are mature. Early onions are also grown to some extent in southwestern Cape Province, but, there, long-keeping cultivars such as Australian Brown predominate. A few onions are exported, but almost none imported.

EUROPE

In Europe are located the two largest import markets for onions, the United Kingdom and West Germany, and three important exporting countries—the Netherlands, Italy, and Spain. The Netherlands exports a higher percentage of its crop than any other country—about 75 to 80 per cent—while Italy exports about 21 per cent and Spain about 14 per cent. In many of the eastern European countries, an effort is being made to increase onion production and *per capita* consumption as well as exports.

SPAIN

For decades Spain has been an important onion-producing country. In the years 1955–58, the land devoted to onions was about 30,000 ha., with a total annual yield of about 600,000 tonnes, of which about 82,000 tonnes were exported. Spain follows Egypt and the Netherlands in the quantity of onions exported. Although onions are widely grown, the most noted district is Valencia, on the east coast. Next to oranges, onions constitute the largest export item from the Valencia district. Onion shipment from Spain begins in May, when the early-maturing 'Babosa' is being harvested, and continues for most of the year. Considerable quantities of 'Babosa' go to Great Britain, but as it is soft and a poor keeper it is not shipped long distances. 'Grano', a firm-fleshed, good-keeping onion, is the one chiefly grown for export. It is seeded in December, transplanted in April, and harvested in late July and August. 'Grano' bulbs that are not shipped from the field are stored in bulk in long, narrow, well-ventilated cribs (Pl. 36(*a*)), and from these cribs continue to move into export markets until March or April. Spanish onions are carefully graded and packed, and are well received in most markets.

THE NETHERLANDS

Onion culture in the Netherlands is chiefly confined to the coastal provinces of North Holland, South Holland, and Zeeland. Only about 4 per cent of the direct-seeded crop is grown outside of these three Provinces. In South Holland most of the production is localized on the island of Goeree-Overflakkee. For the years 1955–58, the Netherlands grew annually an average of 168,000 tonnes of onions on 6,000 ha. About 75 per cent of the direct-seeded crop is exported, 5 per cent is processed, and 20 per cent is used for home consumption. Onions are exported throughout the year (Fig. 2). In general, exports are highest in October, declining to a low point in May, June, and July. Onions are shipped to many countries, but Great Britain and West Germany are the chief recipients (Table VII). From March to June, Egyptian onions compete with those from the Netherlands on the British and West German

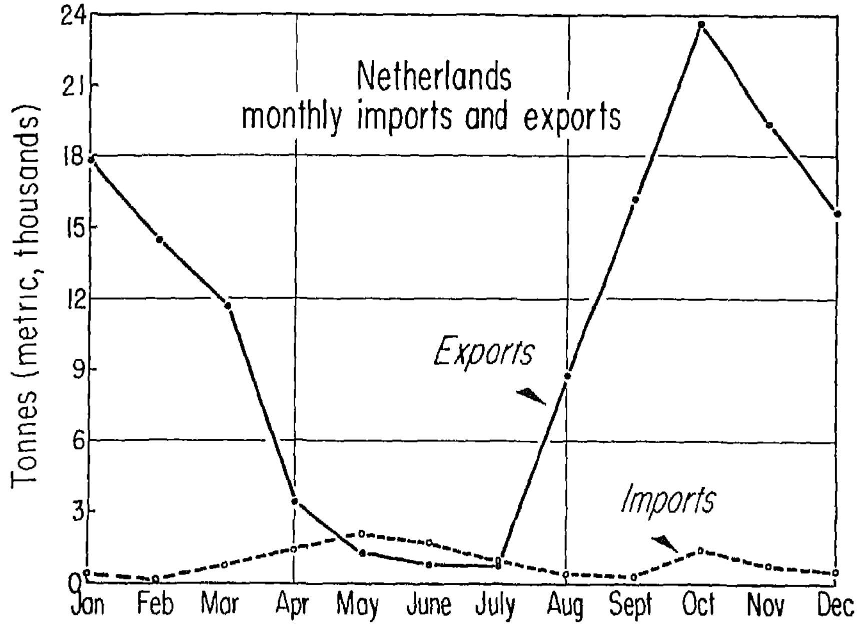

FIG. 2.—Netherlands exports and imports of onions, shallots, and garlic, by months, averages for 1955–58. The Netherlands leads the world in yields per hectare, and exports most of its crop.

markets, while Spain is a competitor throughout most of the year. The Netherlands onion importations are chiefly from Egypt, but some arrive from Hungary, Chile, Italy, and other countries. Imports exceed exports in May, June, and July, but are never very large.

UNITED KINGDOM

The United Kingdom produces about 48,000 tonnes of onions annually. In addition, it is the largest import market in the world, importing well over 200,000 tonnes each year. Before World War II about one-tenth of the market supplies were home-grown. During the war, imports ceased and plantings increased until they reached a maximum in 1944 of some 6,000 ha., about half of which were in the fenland areas of eastern England. After 1948, plantings again decreased, and now remain at about 3,000 ha. Onions are imported throughout the year, the main sources of supply being Spain, the Netherlands, and Egypt, with additional amounts coming from France, Poland, Chile, the Republic of South Africa, Italy, Cyprus, and other countries. Imports are lowest during September and October, when English onions are being harvested. Receipts are heavy from the Netherlands from November to April; from Spain, from November to March and from May to August; and from Egypt, from March to June.

TABLE VII

NETHERLANDS EXPORTS OF ONIONS, SHALLOTS, AND GARLIC, BY COUNTRY OF DESTINATION, 1955–58

(A. S. Tuinman, Netherlands Embassy, Washington, D.C.)

Country of destination	Tonnes (metric, thousands)				Averages—1955–58	
	1955	1956	1957	1958	tonnes	Per cent
Great Britain	54·2	57·7	71·4	81·0	66·1	49·3
Germany, West	36·1	47·3	51·3	51·1	46·5	34·7
Belgium–Luxemburg	8·0	5·1	3·4	4·2	5·2	3·9
Germany, East	—	0·1	3·1	5·8	2·3	1·7
Sierra Leone	1·3	1·3	1·8	2·6	1·7	1·3
Hungary	—	3·3	0·1	3·5	1·7	1·3
France	1·7	0·0	0·1	3·9	1·4	1·1
Ireland	2·0	1·3	1·4	0·9	1·4	1·1
Norway	1·1	1·1	1·3	0·8	1·1	0·8
Sweden	1·6	0·4	0·3	1·0	0·8	0·6
Trinidad	0·6	0·3	0·2	1·1	0·5	0·4
Surinam	0·4	0·4	0·5	0·5	0·4	0·3
Netherlands Antilles	0·4	0·3	0·3	0·4	0·4	0·3
Other countries	1·9	4·2	2·9	8·8	4·4	3·3
Total	109·1	122·9	138·1	165·6	133·9	100·0

0·0 = less than 100 tonnes.
— = no data available.

ITALY

Italy is one of the more important onion-producing countries of the world. For the years 1956–60, annual production was about 300,000 tonnes. Production increased from about 240,000 tonnes[1] in 1956 to about 363,000 tonnes[1] in 1960. Yearly exports vary from 60,000 to 70,000 tonnes.[1] Most exports go to West Germany, but many other countries are recipients of Italian onions. The onion harvest in southern Italy begins shortly after it starts in Egypt and Spain. The export peak is reached in early spring, although some onions are shipped throughout the year. Onions for export are graded as to size, depending upon destination, and are shipped mostly in 25 kg. sacks. Italian cultivars are noted for their mild flavour. The red 'Tropea', grown extensively in the vicinity of Catanzaro in the province of Calabria, is a favourite in United States markets.

The most important onion-producing region is Emilia in northern Italy, where about 100,000 tonnes were produced in 1960—chiefly near Parma, Cesena, Ravenna, and Bologna. The Campania region is next in importance, and includes the district of Mondragone (between Rome and Naples), Scafati near Pompeii (on the southern slope of Mt Vesuvius), and the Salerno coastal area. Other regions, in order of decreasing importance, are Piedmont, Sicily, Puglia (the Barletta coastline between Bari and Andria), and Lazio (north of Rome).

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[1] As explained in the Preface (p. xvi), the figures obtained from individual countries do not always agree with the F.A.O. figures given for example in Tables I, II and III.—*Ed.*

Seeding by machine is practised very little in Italy, except in the districts around Ferrara and Bologna. In the vicinity of Parma and most other districts of northern Italy, seed is broadcast in the field in February, and the crop is harvested in late August and early September. When the transplant method is used in northern Italy, seed is planted in January and transplanting is done in February and March. In southern Italy the climate is mild and the crop is over-wintered. For the early spring crop, seed-beds are prepared in late July, transplanting is done in October, and the onions are ready for harvest in March. For the production of summer onions, seed-beds are prepared in August and September, the crop is transplanted in November and December, and harvesting is started towards the end of June.

Yields in Italy average about 20 to 25 tonnes per ha., but may go as high as 35.

WEST GERMANY

The Germans call the onion 'the queen of the kitchen', because it plays such an important role in their cookery. West Germany is second only to the United Kingdom in the amount of onions imported. For the years 1954–58, average annual imports were about 118,000 metric tonnes. During this same period, domestic production averaged about 26,000 tonnes per annum. Onions are grown around the large cities and in the industrial districts, such as the Ruhr. An important producing district is the upper Rhine plain between Mainz and Heidelberg. Zittau is the principal cultivar, accounting for almost 90 per cent of the production.

FRANCE

France is one of the more important onion-producing and onion-consuming countries of Europe. This is to be expected in a country that is noted for its onion soups and other flavourful dishes. During the years 1955–58, France produced annually about 168,000 tonnes of onions; during this time the yearly imports averaged about 20,700 tonnes. Many onions are grown around and to the south of Paris, in the Rhône Valley of southern France near Avignon and Saint-Rémy-de-Provence, and in the Loire Valley near Angers, Saumur, and Nantes.

POLAND

In Poland the area planted to onions increased from 7,500 ha. in 1947 to about 13,000 ha. in 1957. Average yields for the whole country are from 13 to 16 tonnes per ha., but, with favourable climate and soil, good farmers obtain 30 tonnes or more per ha. In 1956 Poland exported 23,800 tonnes of onions, 15,000 of which went to England and the remainder to Czechoslovakia, West Germany, East Germany, Sweden, Norway, Finland, and Switzerland. Wolska is the most widely-grown cultivar. Most of the onions are direct-seeded in the field about April 10th to 20th, and harvested from August 25th to September 10th. In the Warsaw district some onions are produced from transplants that are started in hotbeds. Large onions for the early market are grown from dry sets. In the Warsaw market these are bunched with the tops on.

HUNGARY

Hungary has long been known as an onion-producing country, and the city of Mako on the southern border, much noted for its onions, has given its name to a cultivar grown there. Onion production, almost entirely from dry sets, is from areas totalling about 3,200 ha.[1] Exports go chiefly to England and West Germany.

CZECHOSLOVAKIA

From 1948–55, Czechoslovakia grew about 4,500 ha. of onions each year, and produced nearly 12 tonnes per ha. Czechoslovakia is an onion-importing country and, being highly industrialized, will probably remain so.

YUGOSLAVIA

The Yugoslavian statistical yearbook for agriculture, 1959, gives 33,100 as the average number of hectares in onions for the years 1955–58, with a mean yield of 161,000 tonnes. This is considerably higher than the amounts reported by the F.A.O. (*see* Table I). The most extensive onion plantings were reported in Serbia in eastern Yugoslavia, where, however, farms are small and yields are low. Onions are both exported and imported, but exports exceed imports.

SWEDEN

Onions are grown chiefly in the south, and on the island of Öland in the Baltic Sea near the east coast. Seed is sown in early April and the harvest is in October. Cultivars are chiefly Zittau Gelbe and Rijnsburger. Sweden imports considerable quantities of onions.

DENMARK

Onions are grown on the island of Amager, near Copenhagen.

FINLAND

In 1957 the area in onions in Finland was about 222 ha. and the total production about 3,900 tonnes. In the south-west part of Finland, onions are produced both from seed and from dry sets. In the central, eastern, and northern parts of the country, onion sets and potato onion (*A. cepa*, Aggregatum group) are used.

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[1] *See* footnote on p. 12.—*Ed.*

EAST GERMANY, ROMANIA, BULGARIA

East Germany, a highly industrialized country, is chiefly an onion importer, although a total of about 4,000 ha. is grown in the Magdeburg, Halle, Erfurt, Gera, and Leipzig districts. Romania grows about 30,000 ha. of onions annually, and Bulgaria about 7,700.

SWITZERLAND

Annual production of onions in Switzerland for the years 1955–58 was about 12,000 tonnes. During this time, imports averaged about 9,800 tonnes a year. Production centres are near Geneva in south-west Switzerland and along Lake Zurich in the northern part of the country.

AUSTRIA

During the years 1955–60, Austria produced annually about 16,000 tonnes of onions (Table I), with annual imports of about 11,000 tonnes (Table II). Dr F. Ehrendorfer (personal correspondence) gives production figures of 45,000 tonnes, with imports of 15,000 tonnes. The chief production districts are in north-east Austria around Raasdorf, and around Laa a.d. Thaya—both in the province of 'Lower Austria'. Planting is done in March and April and the crop is harvested during July to September, with the peak in August. Yellow cultivars predominate. Most Austrian imports are from Egypt and Italy.

Asia

Among Asian countries, India is the largest exporter of onions. Iran, Japan, Lebanon, the Malayan Federation, Syria, Taiwan, and Thailand, are also exporting countries.

JAPAN

Although mention of Japan usually brings to mind *Allium fistulosum* and other eastern species of *Allium*, and although *A. cepa* was introduced into Japan comparatively recently, the cultivation of this last species has spread throughout the country, and today Japan is second only to the United States in the total amount of bulb onions produced. Annual production for 1955–58 was about 800,000 tonnes from approximately 46,700 ha. Between 1954 and 1958, exports averaged about 8,700 tonnes. The main producing areas are in the western half of the country in the Prefectures of Osaka, Hyogo, Wakayama, Shizuoka, Aichi, and Fukuoka. In these areas the seed is planted in seed-beds in September, and the seedlings are transplanted into the field in early winter. In Hakkaido, northern Japan, where the summers are cool, the crop is direct-seeded in the field in the spring, and harvested in the autumn.

INDIA

Not so very long ago the onion was used in India chiefly for seasoning, but today its use as a food is rapidly increasing. The land devoted to onion production is about 60,000 ha., exclusive of kitchen gardens. India supplies its own markets, and between 1954 and 1958 exported between 28,000 and slightly over 68,000 tonnes annually to other Asian countries. Both the small, pungent, cluster-type, and the large, sweet onions are grown. The former are from ½ to 1 in. in diameter, the latter from 2 to 4 ins. The dry-set, transplant, and direct-seeding methods, are all used for growing the crop.

CHINA (*Mainland*)

Other species of onions, such as *Allium fistulosum*, *A. tuberosum*, and *A. sativum*, have been used for centuries in China, and are grown there today much more extensively than *A. cepa*. The last-named bulbing onion is grown to a limited extent throughout China, and is found on the larger markets, but not in such quantities as are the other cultivated Alliums.

TAIWAN

Taiwan has progressed from an importing country to one that is largely self-sustaining, and currently exports onions to Singapore, Hong Kong, Thailand, and Okinawa. Onions are raised as a winter-transplanted crop in rotation with rice. The best-adapted cultivars are Excel and Early Grano, and most of the seed comes from the United States.

PHILIPPINES

The planted area is about 4,000 to 5,000 ha., but, in addition, some onions are imported. The most important onion-producing province is Nueva Ecija, on Luzon, which produced 5,460 tonnes on 1,590 ha. in 1959. Total production that year in the Philippines was 12,645 tonnes. Most onions are grown in rotation with rice, being usually transplanted after rice in December, and harvested before the rains start in May. Cultivars are Excel, Granex, Red Globe, and some Red Creole. Most of the seed comes from the United States.

IRAQ

The onion is one of the more important crops in Iraq. As a rule, domestic supplies are adequate, but occasionally imports are necessary. The crop is grown chiefly in the central and northern parts of the country. Planting is done on ridges or in basins, depending upon the type of soil. Good storage facilities are not available, so growers leave the mature crop in the dry ground all summer, weeds being left to protect the bulbs from the hot sun. Bulbs are dug whenever they are needed for marketing. Dry sets are planted in the spring, and transplants are used in the autumn. The two principal cultivars are Abiadh (white) and Ahmer (red), both of which are good keeping types.

IRAN

Some onions are grown near the Caspian Sea in the north of Iran, and in the coastal areas of the extreme south; but the crop is more important on the plateau areas, where its cultivation is quite general. The Iranians are rather fond of onions, and the bulbs can be found on the markets throughout the year. Red, yellow, and white, mostly flat, cultivars are grown, with the red types predominating. The flavour of most of the cultivars is rather mild, and their keeping quality is good.

UNION OF SOVIET SOCIALIST REPUBLICS

Vvedensky (1946) states that there is large-scale production of onions in the central zone of the European part of the Soviet Union, and considerable cultivation in Trans-Caucasia and central Asia. Cultivation is rare in Siberia and the Far East.

AUSTRALIA

In 1956–57, Australia produced 54,000 tonnes of onions on 3,790 ha. Annual exports average about 3,000 tonnes. Onions are grown to some extent in all states except the Northern Territory, but the most important areas are in Victoria and Queensland, these two states accounting for more than 80 per cent of the total production in Australia. In Victoria the major portion of the crop is grown in the southern part of the state. Early onions for immediate sale make up about one-third of the production, and are grown in market gardens near the large cities. The late crop is stored, and consists chiefly of the long-keeping, tough-skinned 'Australian Brown'. In Queensland, onion production is largely restricted to the Lockyer district, where early-maturing selections of 'Hunter River Brown', 'Hunter River White', etc., are grown under irrigation.

II

HISTORY

LINNAEUS (1753), in his *Species Plantarum*, did not give the native home of *Allium cepa*. Likewise, Don (1827) and Regel (1875), the two post-Linnaean monographers of *Allium*, did not know its native home. Candolle (1885) reported that it had been collected by several botanists in widely different localities in western Asia. These collections, and the fact that it had unrelated names in several languages, suggested to Candolle that *A. cepa* had been domesticated independently in several places, and led him to suppose that it occupied a vast area in western Asia extending perhaps from Palestine to India. Today, however, its occurrence as a wild plant is still in doubt. The very competent botanist Boissier (1882) considered a plant collected in northern Iran, which differed from cultivated material only in the smaller size of its umbel, to be *A. cepa*. Vvedensky (1946) lists *A. cepa* as a cultivated plant only, and Stearn (in Hooker, 1947) does not list it in the *Flora of British India*.

Although there is still doubt as to whether *A. cepa* exists today as a wild plant, most botanists believe that it had its origin in an area including Iran, Pakistan (West), and the mountainous countries to the north (Regel, 1887). Vavilov (1951) cites this general region (although not so far west as Iran) as its centre of origin, and the four closely-related species listed by Vvedensky range from northern Iran north-eastwards as far as the Altai region, three of them occurring in the Tien Shan.

IN ANCIENT EGYPT

While the place of origin of *A. cepa* is still a mystery, there are many documents, from very early times, which describe its importance as a food and its use in art, medicine, and mummification. Our information comes chiefly from Tackholm & Drar (1954), who review the work of many authors and give an extensive bibliography which is of great value to students of history. According to these authors, onions and garlic have always been a popular food in Egypt. Labourers eating onions are depicted in mastabas (tombs) of as early as the Ist and IInd Dynasties (about 3200–2780 B.C.). An account which is often found in literature is that, when the Greek historian Herodotus (about 484–425 B.C.) visited the pyramids at Giza, he was shown a hieroglyphic inscription which a translator interpreted as saying that the pyramid builders consumed radish, onion, and garlic, valued at a sum corresponding to 1,600 silver talents. Although recent authors have misgivings regarding this interpretation,[1] nevertheless, the pyramid builders must have consumed a great quantity of vegetables, including onion and garlic, which were among the popular crops of Egypt.

One of the most important testimonials to the use of onions as a food in ancient Egypt is from the Bible. The Israelites complained bitterly about their hardships while being led by Moses from Egypt to the land of Canaan, 'We remember the fish which we did eat in Egypt freely; the cucumbers, and the melons, and the leeks, and the onions, and the garlick' (Numbers xi, 5). The time of the exodus from Egypt is thought to have been about 1500 B.C. Garlic and onion, among other crops, are also mentioned in the Koran, Part 1: 61.

In Egypt the onion is mentioned as one of the funerary offerings as early as the IIIrd and IVth Dynasties, during the early part of the Pyramid Age (about 2780–2100 B.C.). Onions are depicted on the banquet tables of the great feasts—both large, peeled onions and slender, immature ones. They were among the offerings placed upon the altars of the gods, together with gourds, cakes, beef, goose or wild fowl, grapes, figs, wine, and the head of the victim. Frequently a priest is pictured holding onions in his hand or covering an altar with a bundle of their leaves and roots. In ordinary offerings they were bound together in a single bundle. On the other hand, it is reported that certain priests abstained from them as unlawful food. In mummies, onions have frequently been found in the pelvic regions of the body, in the thorax, flattened against the ears, and in front of the collapsed eyes. Flowering onions have been found on the chest, and onions have been found attached to the soles of the feet and along the legs.

IN INDIA

The onion must have been grown in India from very ancient times, as it is mentioned in the *Charaka-Samhita*, a famous early medical treatise of India. Charaka, who probably lived about the beginning of the Christian era, based much of his material upon the teachings of an earlier authority of about the sixth century B.C. Many virtues are attributed to the onion and garlic by Charaka. They were said to have diuretic properties, to be beneficial to the digestive tract, to be good for the eyes, to act as a heart stimulant, and to be useful as an anti-rheumatic remedy. On the other hand, on account of its odour and stimulating action, the onion was looked down upon in India as a tamasic food, i.e. food inappropriate for those pursuing a spiritual life. Therefore, orthodox Brahmins, Hindu widows, Buddhists, and Jains considered onions a forbidden vegetable. The prejudice must have been widespread, for F. Tsing, a Chinese Buddhist pilgrim who visited India in the seventh century A.D., and who left a valuable account of the country in his time, mentions that none of the people of the five parts of India ate any kind of onions. He further states that, 'as onions have a foul smell and are impure, they are not permitted to be eaten except in case of illness' (personal correspondence from Dr B. Sen, Vive Kanada Laboratory, Almora, India).

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[1] A. Fakhry (1961) notes, 'Like his descendants of the present day, the "interpreter" was inventing a translation for an inscription which he certainly could not read!'

DIOSCORIDES AND THE HERBALISTS

The studies of Dioscorides (ed. Gunther, 1934), a Greek physician, compiled during the first century A.D., are claimed by many to be the chief source of information and inspiration for the herbalists of all nations during the following fifteen centuries. He claimed that all onions are burning, gas-forming, exciting to the appetite, cause thirst, are rarifying to the humours (liquids) of the body, stirring, emetic, cause ballooning of the belly and opening of orifices of the blood vessels, and are useful for relieving haemorrhoids. The juice, mixed with honey and placed in the eye, was said to be useful for weakness of vision, for white clouds, and for incipient cataract. Dioscorides believed the decoction to be a very strong diuretic.

As late as the sixteenth century, the herbalists were still actively engaged in their profession. While Shakespeare was writing plays and acting on the London stage, and while the Spanish Armada was sailing the high seas, a number of English gardeners were collecting plants from all parts of the world, determining their adaptation, and studying their culinary and medicinal values. The most noted of these was Dr John Gerard, a prominent London surgeon, who published his findings in 1597. He claimed that raw onions were not nourishing and that boiled onions were only slightly so. To onions he assigned many medicinal values, but most of these remedies had been listed earlier by other herbalists and pharmacologists, so they are probably not original with Gerard (Arber (1938) gives an interesting account of Gerard's plagiarisms). He said onions caused headaches, hurt the eyes, made man dim-sighted, and caused windiness and over-sleepiness, especially when eaten raw.

INTRODUCTION AND PERTINENT CHARACTERISTICS

We know very little about how or when the onion was introduced into different countries. According to Helm (1956), the cooking onion was popular in Germany at the start of the Middle Ages. The onion is one of many crops for which the Americas are indebted to the Old World. No doubt, it was brought to the New World many times by travellers and early settlers. The early seed catalogues describe onion bulbs of red, yellow, and white colour; of oblate, globe, and spindle shape; of different flavours; and of different dates of maturity. A comprehensive study of cultivars grown in the United States was made by Magruder *et al.* (1941*a*). They described twenty-one cultivars that accounted for about 85 to 90 per cent of the seed used in the United States at that time. Characters considered were season of maturity, leaf colour, plant height, dry scale characteristics, shape, flavour, and storage quality. Also included were a few remarks about the origin or early history of the different onions, and a list of synonyms.

Considerable new information about the onion has been accumulated since about 1900. Some of this has given us a new insight into disease control, adaptation, cultivar improvement, and the commercial possibilities of manufactured products. Presented here are those items which we consider to have had the greatest impact on the onion industry during the first six decades of the twentieth century. Among the various contributions we must include those on onion diseases made by Dr J. C. Walker and his associates at the University of Wisconsin. Their investigations were chiefly concerned with the influence of environmental conditions on the development and spread of organisms, and with methods of control. These studies did much to help us control onion diseases—by introducing good sanitation, proper curing and storing practices, the use of fungicides, and the planting of resistant cultivars. These workers were the first to show that a definite chemical substance, a phenol, present in the outer dry scales of coloured onions, was responsible for resistance to the smudge organism. Many citations to these studies of Walker and his colleagues are given in the bibliography.

The investigations of Garner & Allard (1920, 1923) gave us the first information about the specific effect of day-length on plants, and showed that bulbing in the onion was dependent upon a suitable length of day. Exploring this field still further, Magruder & Allard (1937) showed that some cultivars required longer days to mature than did others. Some plants bulbed satisfactorily at a day-length of 10 hours; others required more than 14 hours. These studies on day-length gave us a better understanding of adaptation, but they did not tell the whole story. Thompson & Smith (1938) showed that, regardless of day-length, onions would not bulb if growing temperatures were too low. For bulbing to be initiated, both temperature and day-length must exceed certain minima.

Temperature also exerts a profound influence on onions through its control of flower initiation. Boswell (1924) observed that sets stored at 0°C. for 6 to 8 months did not bolt as readily as sets stored at 4·4° and 10°C. To determine what effect temperature might have on seed production, H. A. Jones (1928) stored mother bulbs of 'Ebenezer' at controlled temperatures for several months before planting. The response was striking: bulbs stored between 7·5° and 12°C. produced earlier flowers, more seed-stalks, and over twice as much seed, as bulbs stored at 3·5° or above 16°C. Many investigators (Thompson & Smith, 1938; H. A. Jones & Emsweller, 1939; Atkin & Davis, 1954) have since confirmed and clarified this role of temperature in onion seed-stalk formation (Pl. 2(*b*)).

During the same period, onion dehydration outgrew its swaddling clothes and became a thriving industry. Although it was a growing concern in the United States at the beginning of World War II, it received a great stimulus during the war because of the need for dehydrated products for the armed forces. The use of dehydrated onions and other dehydrated products was one way to conserve valuable shipping space. The success of onion dehydration has been largely a matter of initiative and enterprise on the part of the industry. For certain purposes the dehydrated product has advantages over fresh onions, and because of this the business continues to expand.

The papers of Cavallito and his co-workers (1944, 1945) are important landmarks in the study of the chemistry of onions. Cavallito was interested in the antibacterial properties of garlic extracts, and succeeded in isolating an active principle. This compound, along with closely related compounds contributing to the fresh odour of garlic and onions, was found to be quite unstable. Moreover, it was found to be formed enzymatically, from precursors in the bulb, only after the bulb was injured. This information changed many of our ideas on onion flavour and taste, which, up to the time of Cavallito's work, had rested on Semmler's (1892, 1892*a*) analyses of steam-distilled garlic and onion oils. The work of Cavallito and his collaborators, of Stoll & Seebeck (1951), and of many others, is becoming increasingly important as processed onion products are more scientifically prepared and more widely used.

During this time, onion breeding also made significant advances. Of importance was the discovery of the male-sterile 'Italian Red 13-53' onion plant, in 1925, in the onion breeding plots of the University of California at Davis. Studies by H. A. Jones & Clarke (1943) showed that this type of male-sterility could be used in the production of hybrids, that entire progenies of plants that were 100 per cent female could be produced, and that these could be maintained through generation after generation. Hybrids were not ready for release in 1943, but a number of true-breeding male-sterile lines that had been developed in the Government glass houses at Beltsville, Maryland, were released to seed companies in 1944. At the same time male-sterile lines were distributed to state experiment stations in the United States and to other countries. In the United States, co-operative breeding projects were initiated between the United States Department of Agriculture and various state experiment stations, and by their combined efforts many excellent hybrids have been developed and released. A number of seed companies are producing hybrid onion seed rather extensively, using hybrids of their own making as well as those released by public research institutions. In 1960, about 40 per cent of the onions grown in the United States were hybrids.

Developing disease-resistant cultivars has become an integral part of many breeding programmes. Stevenson & Jones (1953) listed known sources of resistance to black mould, smudge, downy mildew, pink-root, purple blotch, smut, and yellow dwarf. A number of short-day, open-pollinated cultivars and hybrids that are highly resistant to pink-root in southern Texas have been developed and introduced (Perry & Jones, 1955).

III

CLASSIFICATION AND IDENTIFICATION

A CLASSIFICATION of plants is an arrangement which usually indicates their relationship to one another. Thus, in the present chapter, we group together as one species the leek, the kurrat, and the great-headed garlic, because they have many characteristics in common, indicating that they were probably derived from the same wild parent. Once such groupings have been established, they are useful to the agriculturist, because related forms usually have other common traits—such as similar susceptibilities to insects and diseases, and like responses to environment. The many resemblances between the common onion and the shallot have long indicated that these two may be closely related, and recent systematic studies have confirmed this, so that the shallot is here treated as a form of the common onion.

Among the cultivated Alliums which we describe, none of the seven species—except possibly the leek (and related forms) and garlic seem to be closely related. Thus, the sequence in which the species are treated has no bearing on their relationships.

Identification, in contrast to classification, refers to the proper naming of the particular plants—i.e. the application of cultivar (horticultural variety), group, and/or scientific Latin names. The onion grower, for example, must be certain of the identity of the onion which he grows, as cultivars are usually narrowly adapted to areas and cultural practices. It is largely through the interest and reliability of seed firms that cultivar names are used consistently.

Correct common or Latin names of the species are important in commerce, and are necessary to such people as the breeder, the pathologist, and the entomologist, who carry out scientific work with onion crops. The pathologist, for example, is usually as much concerned with the correct name of the host as with that of the pathogen. Fortunately, the few species of onions that are grown for food are usually not difficult to identify, and the photographs and brief descriptions presented here should enable anyone to name them with little doubt. However, the flower-garden Alliums, and some species that are grown to a very limited extent for food, as well as others not known in cultivation but sometimes gathered from the wild for eating, and several species that invade our fields and gardens as common weeds, are not described here. The identification of these onions, if their native country is unknown, is no easy task. Because the descriptions given here are confined to the few species which are grown extensively for food, additional information is given on the characteristics and distribution of the genus as a whole, and references to the more important literature are included.

THE GENUS *Allium*

Anyone interested in onions soon learns that the genus *Allium* is placed in the Lily family (Liliaceae) by some authors and in the Amaryllis family (Amaryllidaceae) by others. While *Allium* resembles the lilies—e.g. *Tulipa*—in that its ovary is free and above the attachment of the other flower parts, it resembles the amaryllids—e.g. *Narcissus*—in its umbellate inflorescence surrounded by a spathe. Its relationship to the latter group is becoming more generally accepted, but information on many points besides those of flower-part arrangement and inflorescence is needed to confirm this position. The problem is complex, and botanists are not yet in general agreement on its solution (Lawrence, 1951, pp. 413–16; Darlington & Wylie, 1956; Traub, 1957).

The genus *Allium* is large, containing 500 or more species. Despite the similarities which bring the species together, the genus is a strikingly diverse one. This diversity has been well characterized by Stearn (1946, p. 18), as follows:

> Up to the present well-nigh 1,100 specific names have been proposed in the genus *Allium* and have to be accounted for by the next monographer, but about 600 of them may prove to be synonyms. Thus reduced, *Allium* will, nevertheless, remain a vast almost unwieldy genus. To understand it, related species must be grouped together and this is no easy task. Difficulty arises from the features which give the genus its fascination—the great diversity of structure which its species display, their many different combinations of characters. No organ remains constant in form throughout the genus and all must be considered in building a natural classification. Much attention has been given to the outward form and the outer coverings of the bulb but very little to its internal structure, which varies immensely from group to group. The vernation of the leaves and the characters of the capsules, seeds and seedlings also offer promising fields of enquiry.

In so diverse a group, what, then, are the characteristics which are common to all species of the genus? How can a plant be recognized as an *Allium?* There is no simple answer. Without giving a detailed list of generic characteristics, we can note some of those which are most useful for identification.

Beyond doubt, the onion odour and taste are of first importance. Some plants which are not Alliums have strong or onion-like odours (species of *Ipheion*, *Androstephium*, *Hesperocallis*, *Tulbaghia*, *Nectaroscordum*, and

Milula), and not all Alliums have a strong alliaceous smell or taste. None the less, the exceptions are few and uncommon, so that for fresh material the smell of crushed tissue is the first test.

While the underground storage structures are quite varied, including rhizomes and storage roots as well as bulbs, the well-defined corms which are common in several related genera are not found in *Allium*. The foliage leaves are all basal, i.e. they are attached to an underground stem, although they may have long sheathing bases, so that the leaf-blades appear, superficially, to arise from an above-ground stem (Pls. 5(*b*), 6(*b*)). No leaves actually arise on inflorescence stems except those which form a part of the inflorescence. All six segments of the perianth are usually petal-like, and are free from one another to below the middle. There are always six anther-bearing stamens, and the ovary stands free and above the other flower parts. The inflorescence is an umbel (Chapter IV), and in the bud is surrounded by a single spathe—i.e. the bracts comprising the spathe are united into a single structure, at least at the base.

Certain genera closely related to *Allium* cannot be distinguished from it by the above combination of characters (Moore, 1953); but they are uncommon or unknown in cultivation, and contain few species.

The great majority of Alliums are known only as wild plants, and most are of little or no economic importance. These wild Alliums are confined to the northern hemisphere, extending in the New World from Mexico northwards, and in the Old World from North Africa and southern Asia northwards. Few or no species are found in humid tropical regions or in dense forests; they are common in open grassland, scrub, and desert, and they range from sea-level to high elevations. Most of the approximately eighty species in North America grow in the western states. In the Old World, Alliums are particularly abundant in south-central Asia. Northwards they become less abundant, until only the chive (*A. schoenoprasum* L.) is found in the Arctic, which it reaches in Europe, the eastern half of Asia, and Alaska-Yukon (Polunin, 1959). Of all the species, only the chive is common to both America and Eurasia, although another, a subspecies of the Eurasian *A. victorialis* L., technically extends into America as it is found in the far-western Aleutian Islands (Hultén, 1943).

With the exception of the chive, our domesticated food-Alliums have come from the Near East or from far-eastern Asia. Although all of the *Allium* species of North America appear to be edible and, in fact, many are collected and eaten (Fernald & Kinsey, 1943), none has been domesticated as a food plant.

While the use of Alliums for food far exceeds their other uses by man, many are important as weeds, as garden ornamentals, as range plants, and in medicine. *Allium vineale* L., *A. triquetrum* L., and several other species, have become infamous as noxious weeds, commonly in countries far from their original homes, and an extensive literature on weedy onions and their control is accumulating (Angove, 1947; Richens, 1947; Iltis, 1949; Warren, 1957). For the flower garden, the common chives and the free-flowering Chinese chives bridge the species that are useful for food and for garden decoration. But it is when we see the robust *A. giganteum* Rgl., the delicate *A. cyaneum* Rgl., and the brilliant yellow *A. moly* L., that we realize the great range of material available for ornamental use. For information on flower-garden species, the articles of Wilder (1936), Stearn (1946), Harkness *et al.* (1946), and Mann & Mann (1960), should be consulted in addition to such standard horticultural works as those of L. H. Bailey (1922, 1949) and Chittenden (1951). Moore (1954, 1955) has prepared one of the best available keys for the identification of cultivated species of *Allium.*

CLASSIFICATION OF THE CULTIVATED ONIONS

CULTIVAR NAMES

It is frequently difficult to apply scientific names to cultivated plants in a clear and uniform fashion—especially to those plants which, like the common onion, have given rise, during a long period of cultivation, to many distinct forms. Within the species *A. cepa* L., several Latin-form names have been used to designate botanical varieties (Latin singular, *varietas*)—e.g. var. *aggregatum* Don (the multiplier and potato onions), var. *viviparum* Metz. (forms with bulbils in the inflorescence), etc. In addition to, but quite distinct from, these botanical varieties, we have named commercial varieties. These usually do not have Latin-form names but are named in the language of the country in which they are developed and used. 'Yellow Globe Danvers', 'Zittauer Riesen', and 'Roja Boina', are commercial varietal names.

The Latin names, which are used throughout the world, are maintained or changed according to international rules adopted to give these names precision and uniformity (Lanjouw, 1956). As cultivated plants present special problems of nomenclature, rules to promote a universally understood terminology for the commercial or horticultural varieties of these plants have also been drawn up (Anon., 1961). These latter rules suggest that the term *cultivar* (a variety arising under culture or domestication) can be used in place of the term *variety* when designating horticultural or commercial varieties, in order to avoid using 'variety' in two distinct senses. As the species *Allium cepa* has both botanical varieties and horticultural varieties, we have in this book designated all horticultural varieties as cultivars.

Unlike the names of the botanical varieties, which are denoted by italicized words in Latin form, the cultivar name is usually taken from a modern language and is not italicized. To distinguish it further, its initial letter is capitalized, and it either follows the word 'cultivar' (or the abbreviation 'cv.') or is placed in single quotation marks. The terms *variety* in English, *variété* in French, *Sorte* in German are equivalents of cultivar, and any of them may be used in its place. Cultivar, however, has the advantage of being understood in many languages and, unlike *variety*, *variété*, etc., is not readily confused with the botanical variety or *varietas* (cf. above).

Improved selections of cultivars have frequently been designated as 'strains', or by other equivalent terms. This category is not recognized by the Code for Cultivated Plants, where the policy is followed that 'any such selection showing sufficient differences from the parent cultivar (variety) to render it worthy of a name is to be regarded as a distinct cultivar (variety) . . .' (Anon., 1961, Art. 12).

GROUP NAMES

While the use of the term cultivar to designate the fancy-named sorts of onions which are grown commercially presents no special problems, the long-used botanical varietal names are sometimes difficult to apply, and, at least in some cases, misleading in their implications.

The International Code of Botanical Nomenclature (Lanjouw, 1956, Art. 28) states: 'Plants arising in cultivation through hybridization, mutation, or other processes which tend to establish recognizable differences from the parent stocks receive epithets, preferably in common language (i.e. fancy epithets), markedly different from the Latin epithets of species or varieties.' Thus it appears doubtful whether the names *aggregatum*, *viviparum*, etc., should have the standing of botanical varieties within *A. cepa*, as, so far as we know, they do not represent wild forms or populations but have, in all probability, arisen in culture as man-made selections from *A. cepa*, and therefore subsequently to its domestication. Also, it may be questioned whether or not such 'botanical varieties' encompass closely related lines or clones, i.e. whether they indicate genetically related groups within the species. For example, the multiplier onion (making up var. *aggregatum* in part) is common throughout much of the world and is quite varied. Its characteristic 'dividing' habit constantly appears in breeding lines of the common large-bulbed forms of *A. cepa*. Few onion breeders doubt that they could produce typical var. *aggregatum* onions by a few generations of selection from many of our large-bulbed cultivars. As a further example, the male-sterile cultivar Italian Red 13–53 reproduces by inflorescence bulblets, and might well be placed in var. *viviparum* were it not for the fact that it is known to have been derived from the cultivar Italian Red (clearly belonging to var. *cepa*) by a minor, albeit important, genetic change.

The Code for Cultivated Plants states: 'Within a species or interspecific hybrid which includes many cultivars (varieties), assemblages of similar cultivars (varieties) may be designated as groups' (Anon., 1961, Art. 13).

We believe that the use of group names—names implying no more than certain morphological similarities—is more suitable for many of the cultivated onions than are the botanical varietal names now used. These group names, unlike those of the botanical varieties, have no official standing as part of the scientific name, but can be inserted when they are of descriptive value. The botanical varietal names should still be used by those who wish to do so. Some of these names have had many years of use and, with their synonyms, form a vital part of the historical literature of the cultivated forms.

The group name, if used, may be placed in parentheses between the Latin binominal and the cultivar name. If the binominal is understood, the group name may be used alone, and is capitalized but not italicized.

Examples of the categories used in the classification of some common Alliums should clarify their use:

	Common name			
Taxonomic category	Common onion	Ever-ready onion	Leek	Rakkyo
Genus	*Allium*	*Allium*	*Allium*	*Allium*
Species	*cepa*	*cepa*	*ampeloprasum*	*chinense*
Group	Common onion	Aggregatum	Leek	(None)
Cultivar (or variety, variété, Sorte, etc.)	'Italian Red'	'Perutile'	'Large American Flag'	'Rakuda'

The name of the cultivar Italian Red (column two, above) can be written out as *Allium cepa* L. (Cepa group) cv. Italian Red, or *Allium cepa* L. (Cepa group) 'Italian Red'. Or the simpler forms *Allium cepa* L. cv. Italian Red, or onion 'Italian Red', may be used. The common name of the species or of the group, e.g. common onion, leek, rakkyo, should not be used as a cultivar name.

IDENTIFYING THE CULTIVATED ALLIUMS

It may be helpful to those attempting to identify the cultivated food-alliums to note that the seven species described below are quite distinct and without intergrading forms. Hybridization between these species is not known except between *A. cepa* and *A. fistulosum*, where the record is well documented and the hybrids, up to now, are quite distinct. Table VIII and Fig. 3 summarize several of the conspicuous differences among the Alliums that are grown for food, and, along with the photographs which follow, should suffice for their identification. If flowers are at hand, the shape of the tissues around the nectary opening should also be examined. Nectar is secreted through a small pore in the side of the ovary adjacent to each inner stamen. The ovary wall around this pore may be smooth (*A. tuberosum*), may be folded into a slight (*A. sativum*) or well-defined (*A. ampeloprasum*) ridge above the pore, or may grow down over

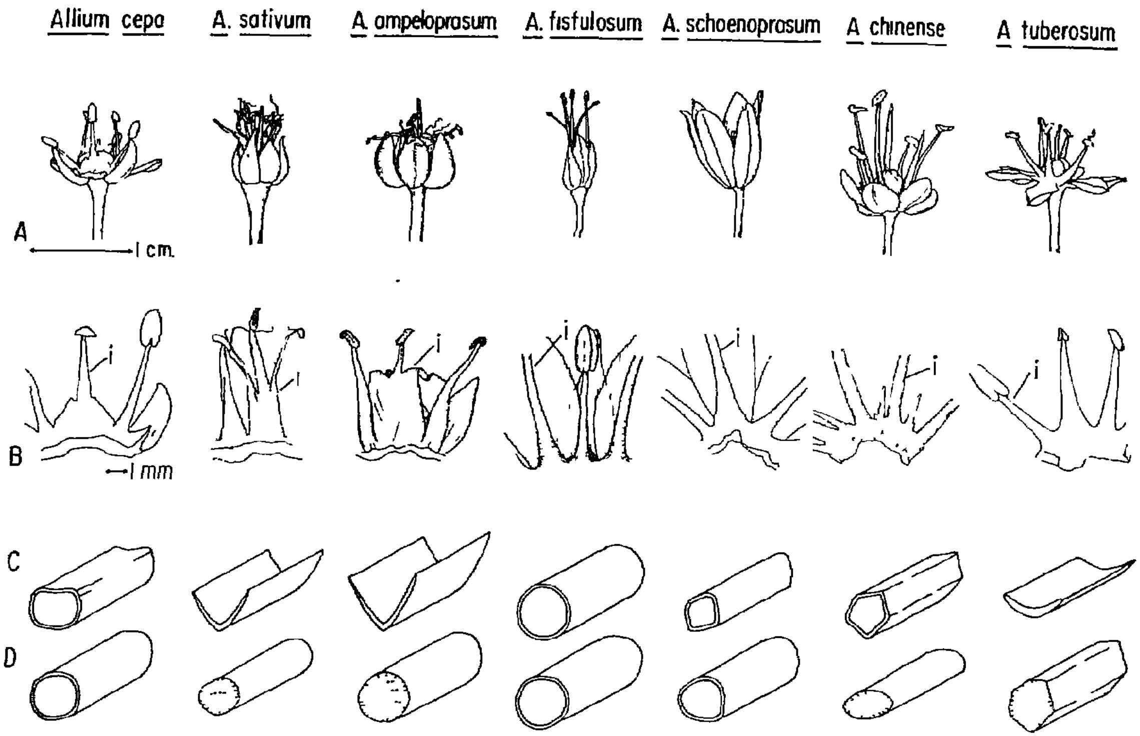


FIG. 3.—Characters for identifying food Alliums. Flowers (A), stamens (B), and cross-sections of foliage leaf-blades (C) and of scapes (D), of the species. Flowers and stamens were drawn with a camera lucida; leaf and scape sections are diagrammatic and not to scale. Inner stamens are indicated by 'i.' The vertical columns in this figure correspond to the horizontal rows in Table VIII.

the pore to form an open (*A. chinense*, *A. schoenoprasum*, *A. fistulosum*) or a nearly closed (*A. cepa*) cavity.

Identification of the groups within the species presents a more difficult problem. Few of the groups are completely distinct, and intermediates can be expected.

In the groups of commercially important Alliums, the naming of cultivars usually requires a first-hand knowledge of all the important cultivars of a particular area. Except as examples, cultivars are not included in the following description of the *Allium* species. The classification we use is:

Allium cepa L.
  Common Onion Group: common onion.
  Aggregatum Group: potato or multiplier onion, ever-ready onion, shallot.
  Proliferum Group: top, tree, or Egyptian onion.
Allium sativum L.
  Garlic. No groups.
Allium ampeloprasum L.
  Great-headed Garlic Group: great-headed garlic.
  Leek Group: leek.
  Kurrat Group: kurrat.
Allium fistulosum L.
  Japanese bunching or Welsh onion. No attempt is made here to group the many varied forms cultivated in China and Japan.
Allium schoenoprasum L.
  Chive. No groups.
Allium chinense G. Don.
  Rakkyo or ch'iao t'ou. No groups.
Allium tuberosum Rottler ex Sprengel.
  Chinese chives. No groups.

THE COMMON ONION (KÜCHENZWIEBEL; OIGNON), POTATO ONION, SHALLOT, ETC., *Allium cepa* L.

The early history of the common onion was reviewed in Chapter II, where it was pointed out that it probably originated in the region of Iran and West Pakistan or in the mountainous areas to the north of that region. It has been in cultivation for 5,000 or more years, and indeed, there is doubt that it exists today as a wild plant. Its specific epithet, *cepa*, is from the Latin name of the onion, *cepa* or *caepa*.

Although they are rarely confused at the present time, Helm (1956), and especially Prokhanov (1930), have indicated how frequently early botanists failed to distinguish between the common onion and the Japanese bunching onion, and how difficult it now is to follow the early agricultural uses of these two. Both species are robust plants (Pls. 3, 8(*a*)); but they differ in flower colour and in the mode of flower opening over the umbel (Table VIII). The almost completely closed flowers of *A. fistulosum*, with their ultimately long-protruding stamens, contrast with the wide-open flowers and relatively short stamens of *A. cepa* (cf. Fig. 3). Plants lacking flowers are more difficult to distinguish. However, all forms of *A. cepa* except the ever-ready onion form conspicuous bulbs, whereas *A. fistulosum* never bulbs. The leaves of *A. fistulosum* are round in cross-section, those of *A. cepa* slightly to markedly flattened on the upper surface.

While the bulbs of *A. cepa* are extremely variable in size, shape, and colour, they are always tunicate—i.e. made up of layers of more or less concentric leaf-sheaths, so that a transverse slice of a bulb may be separated into a number of rings. Of the other cultivated Alliums which form well-developed bulbs—i.e. bulbs that are well over twice as thick as the neck immediately above them—only rakkyo, *A. chinense*, shows these rings.

HORTICULTURAL GROUPS

The horticultural forms of *A. cepa* may be placed in three groups; the Common Onion group, the Aggregatum group, and the Proliferum group.

Common Onion Group. Bulbs large, usually single; inflorescence typically lacking bulbils; plants almost always produced from true seed.

It is to the Common Onion group that the great bulk of our cultivars belong—indeed essentially all of the commercially important bulbing onions (Pls. 3(*a*), 17(*a*)). These show an extreme variation in bulb colour and shape, in their response to temperature and photoperiod, in storage quality and pungency, and in many other characteristics. An excellent summary of this variation, as shown by many American cultivars, is given by Magruder *et al.* (1941*a*), and Chapters VI, VII, and VIII of the present book deal further with this variation. For botanical synonyms, *see A. cepa* var. *cepa* in Helm (1956).

Aggregatum Group. Ground bulb with many lateral bulbs or shoots; inflorescence typically lacking bulbils, producing seed or sterile; multiplication almost exclusively vegetative.

In this group, that is characterized by bulbs which multiply freely and which are usually used for propagation, we place three rather distinct forms: the potato onion, the ever-ready onion, and the commercial shallot of the United States and Europe (commonly listed as *A. ascalonicum*).

Potato or Multiplier Onion (Pls. 3(*b*), 4(*a*)). In 1827, George Don described as variety *aggregatum* a garden form of *A. cepa* having round,

TABLE VIII

CHARACTERS USEFUL IN IDENTIFYING THE COMMON FOOD ALLIUMS

Species	Time of flowering	Flower colour	Opening of flowers in umbel	Bulbils in inflorescence	Food-storage structures
Common onion, *Allium cepa* (incl. shallot)	Spring	Green-white	Irregular	Absent in most cultivars	Foliage leaf-bases; also bladeless leaf-sheaths
Garlic, *A. sativum*	Spring (or non-flowering)	Lavender (flowers always abort)	Irregular	Always present	Massive bladeless sheaths (cloves); no storage in foliage leaf-bases
Great-headed garlic, *A. ampeloprasum* (incl. leek and kurrat)	Spring	White to purple	Irregular	Usually absent	Cloves as in garlic, but of two sizes; variable or lacking in leek and kurrat
Japanese bunching onion, *A. fistulosum*	Spring	Pale yellow	From apex to base of umbel	Absent in most cultivars	Foliage leaf-bases only; bulbs poorly developed
Chive, *A. schoenoprasum*	Spring and summer	Purple, rarely white	From apex to base of umbel	Rarely present	Foliage leaf-bases only; bulbs poorly developed
Rakkyo, *A. chinense*	Autumn (after summer rest)	Lavender	Irregular	Absent	Foliage leaf-bases only; bulbs well developed
Chinese chive, *A. tuberosum*	Mid- to late-summer	White	Irregular	Absent	Conspicuous rhizomes; bulbs poorly developed

depressed, aggregate bulbs with brown outer coats. So far as he knew, it did not flower, and it was called the underground or potato onion. Later, F. Alefeld described a similar form as var. *solaninum*, and L. H. Bailey described it as var. *multiplicans*—names which must be considered synonyms of Don's earlier name.

The potato onion is quite distinct, in that it forms fairly large, oblate bulbs (greater in breadth than in height) with numerous laterals enclosed by the outer scales. These laterals produce separate tops and bulbs in their second year of growth, and the number of bulbs formed from a single bulb varies, according to Helm's observations (1956), from 3 to 20. The potato onion is probably always propagated by bulb divisions. Reports in the literature (Don, 1827; Goff, 1888; Bailey, 1922; Millán, 1952; Täckholm & Drar, 1954; Helm, 1956) indicate that flower-heads either do not appear or do so only sporadically. Helm states that many bulbs flowered at Gatersleben in 1955, but that 'seed set was sparse and the germination very poor'. Hybrids have been obtained between the potato onion and Common Onion group cultivars.

Ever-ready Onion. Fortunately, we have an excellent account of the ever-ready onion by W. T. Stearn (1943), written during World War II, when such typically home-garden perennial onions as the Welsh onion, potato onion, and ever-ready onion served to supplement the short supply of commercial bulb onions in Britain. Stearn points out that the Welsh or Japanese bunching onion, once an important spring market onion in England, had almost passed out of cultivation by the start of the present century, and that its common name had been largely transferred to the ever-ready onion, a form of *A. cepa* having a similar habit. The ever-ready onion 'resembles the biennial, large-bulbed forms of *A. cepa* in flower as in leaf-section, but is of perennial and prolific growth, has a much narrower bulb and narrower leaves, a shorter flower-stalk and smaller umbel'. Stearn gave the name 'Perutile' (meaning 'very useful') to the cultivar grown by Mr Clarence Elliot at Stevenage, England, and marketed by him as the Welsh or ever-ready onion. This cultivar has reddish bulb-coats and leaves scarcely 1 cm. wide by some 40 cm. long. The lower part of the 40 to 55 cm.-high scape is inflated, as is typical of *A. cepa*, but the plant rarely flowers. The plants are 'increased by division, never by seeds'; a single bulb planted in March produced 10 or 12 bulbs by autumn. It is implied, but not specifically stated, produce a cluster of bulbs from a single planted bulb. The plants are usually of small stature, but the flowers and inflorescence are typically those of *A. cepa.* Atkin (1953) crossed Common Onion-group cultivars with shallot, and stated that 'Complete normality of meiosis, high pollen viability, and high seed set in the F_1 indicate there is no sterility in the F_1. High germination percentage of seeds and high seedling viability in the F_2 indicate that there is no degeneration in that generation.' He adds, later, 'In view of the above facts it is concluded that *A. ascalonicum* (i.e. the shallot as grown in the United States) is not a separate species, but rather a variety of *A. cepa.*'

The taxonomic problem confronting Atkin and other horticulturists working with the shallot, stemmed largely from the vague characterization of *Allium ascalonicum* in the literature—its differentiation from *A. cepa* primarily by its smaller stature. Stearn (1960) has finally set the matter straight by showing that the Linnaean type of *A. ascalonicum* is a specimen of a wild Palestinian plant that has long been known under the name *A. hierochuntinum* Boiss. This species is in no way related to the cultivated shallot, and has never been under cultivation. Stearn was able to trace, in part, the erroneous application of the name *A. ascalonicum* to the cultivated shallot, and suggests that the confusing epithet *ascalonicum* be rejected. However this name is used, it cannot be applied to any cultivated plants that we know as shallots. Morphological and genetic evidence indicates clearly that the latter are forms of *A. cepa.*

Some shallot clones flower freely and set abundant seed; others flower rarely, if at all. All are increased vegetatively; at least some of the clones which produce seed are heterozygous, and seedlings do not come true to type. Shallots differ from the ever-ready onion in that they produce well-defined bulbs, the tops die, and the plants enter a state of rest as in the Common Onion group. They differ from the potato or multiplier onion mainly in bulb size, the laterals separating as individual bulbs rather than forming aggregates within a single large bulb. A number of cultivars are known, e.g. 'Louisiana Pearl'. The 'Louisiana Evergreen' shallot is a species hybrid, a cross between 'Louisiana Pearl' and *A. fistulosum.*

Proliferum Group. Ground bulbs sometimes poorly developed; inflorescence bearing bulbils, true seed usually lacking; reproduced vegetatively by inflorescence bulbils.

As was pointed out by Helm, the proliferous inflorescences may be extremely varied, carrying mixtures of bulbs and flowers, or bulbs only. The bulbs, while still attached to the plant, may bear no tops, or may have leaves or leaves and scapes—the latter again bearing bulbs with scapes, etc. Names, such as top onion, tree onion, Egyptian onion, and Catawissa onion, have been applied to these forms.

Prokhanov (1930) and others (*see* Helm, 1956, p. 165) have concluded that all proliferous forms belong to *A. fistulosum*, and this is followed by Millán (1952), who lists *A. cepa* var *viviparum* as a synonym of *A. fistulosum* var. *viviparum* Makino. Both species appear to have proliferous forms, and the confusion on this point stresses the difficulty of differentiating between vegetative forms of *A. cepa* and of *A. fistulosum* (*see* pp. 31–32, 42).

Allium canadense L., a North American species with races in which the umbels are bulbiferous (Ownbey & Aase, 1955), has been confused with the proliferous races of *A. cepa* (Sturtevant, 1919).

Despite the abundance of common names that have been applied to the forms of the Proliferum group, they are almost entirely of home-garden culture, and no cultivar names appear to have been used.

GARLIC (KNOBLAUCH; AIL COMMUN), *Allium sativum* L.

Allium sativum (sativum = cultivated), like the common onion, has long been known only as a cultivated plant (Chapter XVIII). Its native home and its existence as a truly wild species have been discussed by Regel (1875, 1887) and Candolle (1885); more recently, Vavilov (1951) and Vvedensky (1946) have considered *A. longicuspis* Rgl. to be its wild ancestor. This species, described by Regel in 1875, is, according to Vvedensky, endemic to central Asia, where it extends from mountainous (southern) Turkmenia north-eastwards in the Pamir-Alai and Tien Shan regions. Vvedensky (1946, p. 187) writes '*A. longicuspis* is the wild race of *A. sativum* L. (garlic), differing in the exserted anthers. In *A. longicuspis*, as in many onions possessing bulbils in the umbel, the flowers apparently do not always develop, and then the anthers are not exserted from the perianth. Observations on this species in cultivation are desirable.'

CHARACTERISTICS

Garlic (Pl. 5(*b*)), with its flat, longitudinally-folded leaf-blades diverging at widely-spaced intervals from its false 'stem', can be confused, among the cultivated onions, only with forms of *A. ampeloprasum* (Pls. 6(*a*), 6(*b*)). From this usually more robust species, it can be distinguished by the absence of small exterior bulblets around the main bulb (compare Pls. 5(*b*), 6(*a*)); and in flowering plants the large umbels of long-stalked flowers of *A. ampeloprasum* (Pl. 7(*a*)) are quite distinctive from the small, bulb-bearing inflorescences of garlic (Pl. 5(*b*)).

The scape of garlic is smooth, round, and solid for its entire length. Many clones of garlic do not produce flower-stalks; or the inflorescence may be partially or not at all exserted, its bulbils forming a swelling somewhere within the false stem, a few inches above the bulb. When the scape is well exserted, it is at first more or less coiled, but later it straightens. The inflorescence spathe is long-beaked and usually splits on one side, remaining attached to the umbel base (Pl. 5(*b*)). Small bulbs, varying greatly in size, are always present in the inflorescence, and the flowers (Fig. 3), which are extremely variable in number or may even be absent, rarely open, but wither as buds.

The composite garlic bulb, made up of numerous smaller bulbs (cloves), is well known (Chapter IV). If very small cloves are planted, or if growing conditions are poor, a single small, solid clove, usually called a 'round', is produced. Rounds, if planted under favourable conditions, give rise to the usual composite bulb. Large rounds, common in the bulbing forms of *A. ampeloprasum*, are not found in garlic (*see* Chapter IV).

HORTICULTURAL GROUPS

Garlic is an extremely variable species; many strikingly distinct clones are known in cultivation and, as might be expected, some of these forms have been designated as botanical varieties of *A. sativum*. Helm (1956) lists the three most commonly recognized varieties: *A. sativum* var. *sativum*; *A. s.* var. *ophioscorodon* (Link) Döll; and *A. s.* var. *pekinense* (Prokh.) Makino. These varieties have, so far as is known, arisen in culture and, in the classification we are following, might be recognized as horticultural groups.

Some thirty clones of garlic, collected from the United States, South America, Europe, and Asia, have been grown at Davis, California, and have been examined carefully for the varietal characteristics described by Helm. Our preliminary data show that, while some of the clones fit into var. *sativum* or var. *ophioscorodon* reasonably well, so many show combinations of characteristics of both varieties that we feel no purpose is served by recognizing these two varieties or by designating horticultural groups to replace them.

The third variety, *Allium sativum* var. *pekinense* (Prokh.) Makino, was first described as a separate species by Prokhanov (1930), who believed it arose as a mutant from cultivated garlic that was being grown in China or Japan. It is differentiated mainly by its broad (over 2 cm. wide) and drooping leaf-blades. From the description and illustrations (Prokhanov, 1930, Figs. 13, 14; Makino, 1956, Fig. 2244), it is difficult to differentiate this variety from our cultivars such as 'California Early', which may grow to a height of a metre or more and have leaves 3 to 4 cm.

wide. Material which we have received from Japan as var. *pekinense* has bolted freely (which 'California Early' does not), but shows no special characteristics that were not observed among other clones. Again there appears to be no reason to separate this particular clone or group of clones as a group apart from the many distinctive 'lines' making up the species.

Fancy-named clones are known in most countries where garlic is grown, and a number of these are mentioned in Chapter XVIII.

ROCAMBOLE

Confusion has long existed over the common name 'Rocambole.' This confusion involved garlic, a closely-related onion (*Allium scorodoprasum* L.), and two common names, 'Rocambole' and 'Serpent Garlic.' These last names are usually used interchangeably and, as 'Serpent Garlic' suggests, are applied to a species with a coiled scape.

Helm (1956) discusses the use of the term 'rocambole' at some length, and presents evidence to show that certain forms of *A. sativum* have been confused with *A. scorodoprasum* since pre-Linnaean times, and that it was to these forms of *A. sativum* that the names rocambole and serpent garlic have been applied. He concludes that the name rocambole should be applied only to forms of garlic with coiled scapes, and not to *A. scorodoprasum*, a species that is native to Europe, western U.S.S.R., and Asia Minor. *Allium scorodoprasum* has inflorescence bulblets and flat leaves; but it differs from garlic in its shorter spathe, lack of numerous cloves of uniform size in its bulb, dark-violet bulb-coats, and other characters. While it has been used for food, it is not known to be in cultivation at the present time.

GREAT-HEADED GARLIC, PEARL ONION, LEEK, AND KURRAT, *Allium ampeloprasum* L.

Allium ampeloprasum L. (ampelos = grape-vine, prason = leek; a species found in vineyards), from which several of our cultivated food Alliums have been derived, is an extremely variable species, ranging as a wild plant from southern Europe and northern Africa through the Middle East into western and southern U.S.S.R. Many botanical varieties have been described (*see* Feinbrun, 1943, for a note on these), and a number of the more distinct forms have at times been named as separate species (cf. Vvedensky, 1946). Few cytological studies have been made of the many wild varieties and, as Feinbrun notes, the controversies regarding classification can be explained and clarified only through comparison of abundant materials from the total geographical range of the species. Certainly the unsettled status of the cultivated forms would be improved by a better understanding of this variable species in the wild.

CHARACTERISTICS

Though extremely variable, the wild *A. ampeloprasum*, and the cultivated Alliums derived from it, have many distinguishing characteristics in common. Most forms of *A. ampeloprasum* (Pls. 6(*a*), 6(*b*), 7(*a*), 7(*b*)) are robust plants with flat, keeled leaves—i.e. leaves that are folded sharply lengthwise—as in the leek. Except in the leek, and to a lesser extent in kurrat, the bulb is well-developed; in the wild forms this usually consists of two thick, bladeless storage leaves (cloves) surrounded by the thin bases of the foliage leaves, which are not storage structures. Among the foliage leaf-bases, and exterior to the large cloves, there are from several to many smaller cloves, which are completely distinct in size and shape from the larger cloves. In wild forms these smaller cloves or bulbs are frequently very numerous (Pl. 6(*a*)), and are commonly present even in the almost bulbless leek (Pl. 7(*a*)). Bulbing but non-flowering plants of *A. ampeloprasum* closely resemble robust types of garlic (*A. sativum*), and these exterior bulblets, never present in garlic, are one of the most useful characteristics separating the two species.

The round, solid scape of *A. ampeloprasum* is usually tall (up to 1 m. or more) and not coiled or curved, and the inflorescence is large and globular. The spathe, which has a long beak (Pl. 7(*a*)), is shed at maturity. Bulbils may be present in the inflorescence, but are uncommon and usually much less conspicuous than in garlic. Although the flowers vary somewhat in detail, they are always globular in shape and never open widely (as they do in *A. cepa*). The stamens, after the pollen is shed, reflex over the tips of the petals and sepals and, because of the breadth of the filaments, form a flaring tube around the style, which gives, in face view, a characteristic appearance to the flower (cf. Fig. 3).

HORTICULTURAL GROUPS

The cultivated forms of *A. ampeloprasum* may be placed in three groups: the Great-headed Garlic group, the Leek group, and the Kurrat group.

Great-headed Garlic Group. Bulbs large, usually of many cloves; flowers mostly sterile, the plants reproducing vegetatively; the cloves (single, bladeless storage leaves) eaten.

Here belong the great-headed or elephant garlic, and probably the pearl onion. Great-headed garlic is a large-bulbed cultivated plant, probably in part the basis of Linnaeus' (1753) description of the species, and of the names *A. ampeloprasum* var. *holmense* (Mill.) Ascherson & Graebner (1905–07) and *A. ampeloprasum* var. *ampeloprasum* of Millán (1952) and Helm (1956). A detailed synonomy of this group is given by Helm.

Plants of the Great-headed Garlic group (Pferdknoblauch, ail d'orient) have the appearance of extremely robust garlic plants and are frequently confused with garlic by home-gardeners (Pl. 6(*b*)). Great-headed garlic flowers freely and may be readily distinguished from garlic by its large, leek-like umbels which usually lack bulblets. Vegetative plants may be distinguished from garlic by the presence of the small bulblets around the main bulb.

Great-headed garlic may produce a cluster of several cloves with a central flower-stalk, or, in non-flowering plants, a single massive clove. Further information on these single cloves or 'rounds' is given in Chapter IV. Great-headed garlic usually sets very few seeds—so far as we know, most clones are relatively sterile hexaploids—and is almost always reproduced vegetatively. Its flavour is somewhat intermediate between that of onion and garlic.

Helm (1956) discusses the pearl onion (or Perlzwiebel) at some length. Pearl onions are small, white bulbs used for pickles, and while to the best of our knowledge they are not grown in the United States, the pickles are imported from Italy and Germany and marketed in specialty-food shops. Each tiny bulb consists of a *single* storage leaf, and so is quite distinct in structure from the small tunicate bulbs of *A. cepa*, which are also commonly pickled. Although bulbs of the latter species are sometimes referred to as pearl onions, this use of the name appears to be rather local. There is some confusion in the literature as to the onions used for pearl onions. Helm believes that they are the small bulblets around the base of the leek plant, their number being increased by the early removal of the flower-stalk. While there seems little reason to doubt, from their structure, that they are derived from *A. ampeloprasum*, we have not secured, for culture, specimens of the plants used in Italy and Germany, and so cannot say whether the parent plants resemble more closely the leek or the great-headed garlic.

Leek Group. Bulbs little or not at all developed; propagated by seed; the elongated foliage leaf-bases (false stem) eaten.

In this group belongs the leek (Porree, poireau), to which Linnaeus (1753) gave the name *Allium porrum*, and which he differentiated from *A. ampeloprasum* by its tunicate, narrow bulb (Pl. 7(*a*)). In the second edition of his *Species Plantarum*, Linnaeus suggested that the leek might be only a variety of *A. ampeloprasum*, and later J. Gay described it as *A. ampeloprasum β porrum*, an interpretation that has been followed to the present by some authors. That the leek is a cultigen not known in the wild state is generally accepted (Regel, 1875; Candolle, 1885; Bailey & Bailey, 1941; Vvedensky, 1946; Täckholm & Drar, 1954; etc.). The resemblance of the leek to wild *A. ampeloprasum* is striking, not only in flowers and foliage, but also in that leeks frequently produce a small number of both the large cloves and small exterior cloves which are so characteristic of *A. ampeloprasum* (*see* leek seed production, Chapter

XIX), and few botanists appear to have doubted that the leek was derived from *A. ampeloprasum*. For these reasons, the leek cultivars, of which many are known, are placed here as the Leek group of *A. ampeloprasum*, and not as the species *A. porrum*.

Kurrat Group. A single, leek-like form of small stature, grown in the eastern Mediterranean region for its edible tops; propagated by seed.

In 1925 a little-studied onion, long cultivated for food in Egypt, flowered in the Berlin Botanic Garden and, the following year, was given the name *Allium kurrat* Schweinfurth ex Krause. Kurrat, as this plant is known in Egypt, resembles a small-statured leek and, according to Täckholm & Drar (1954), has long been called *A. porrum* by botanists in Egypt (Pl. 7(*b*)). It is distinguished from the leek by its narrower leaves, small stature, and certain characteristics of its stamens.

Kadry & Kamel (1955) hybridized kurrat and leek and studied the parents and hybrids cytologically. They found that the leek is an autotetraploid (*see also* Levan, 1940), as is kurrat. Reciprocal crosses between leek and kurrat produce morphologically intermediate and highly fertile F_1's. Kadry & Kamel conclude, 'In view of the cytological studies carried out by the authors, *A. kurrat* and *A. porrum* may be considered as one species, or two closely related ones.' Kurrat is known only in cultivation, and 'Like *A. porrum*, it may have originated from *A. ampeloprasum*' (Täckholm & Drar, 1954). Because kurrat appears to be a cultigen derived from *A. ampeloprasum*, and because it so closely resembles, and is completely interfertile with, the leek, it is treated here as a form of *A. ampeloprasum*. There is no indication, in the literature, of any named cultivars.

JAPANESE BUNCHING ONION OR WELSH ONION (WINTERZWIEBEL; CIBOULE), *Allium fistulosum* L.

As the common onion, *A. cepa*, has been the principal vegetable onion of southwestern Asia and Europe, so the Japanese or Welsh onion has been, since prehistoric times, the main garden onion of China and Japan. The name Welsh, suggesting that this onion may have originated in Wales, is possibly a corruption from the German 'welsche'—i.e. foreign—a name applied when this onion was introduced into Germany, probably at the end of the Middle Ages (Stearn, 1943). Stearn adds that it has never been commonly grown in Wales. The name *fistulosum*—i.e. a hollow tube—appropriately describes the strongly-inflated leaves and scape.

The Japanese bunching onion is not known as a wild species. A near relative, *A. altaicum* Pall., differs in having well-developed bulbs with brown parchment-like coats and shorter flower pedicels, and is distributed in northern Mongolia and adjacent mountainous areas to the north. Another related species of small stature, *A. microbulbum* Prokh., is apparently known only in cultivation. Both of these species are geographically widely separated from *A. fistulosum*, and their possible relationships are in dispute (Prokhanov, 1930; Stearn, 1943; Vvedensky, 1946).

Allium fistulosum, like *A. cepa*, is a vigorous and usually robust garden plant with fistulose leaves and scape (Pl. 8(*a*)). While flowering plants are easily distinguished, the purely vegetative plants of these two species may be confused. The bulbs of *A. fistulosum* become only slightly enlarged, so that plants which bulb at all strongly are not members of this species. The shape of the leaf in cross-section is probably the most commonly-used differentiating character; the leaf of *A. fistulosum* is almost perfectly circular, while that of *A. cepa* is flat on the upper or inner surface (Fig. 3). At its best this character is quite striking, but some forms of *A. cepa* show only occasional and slight flattening of the leaves. More satisfactory characters for separating non-flowering (vegetative) plants of these two species need to be found.

The round, fistulose scape of the Japanese onion is regularly inflated for its whole length, never showing a localized swelling as does that of *A. cepa* (cf. Pls. 3(*a*) and 8(*a*)). The spathe of *A. fistulosum* is short, has no long tip, and remains attached to the inflorescence base after flowering. The flowers (Fig. 3), usually a pale yellow and without a contrasting mid-nerve on the perianth segments, never open widely, as do those of *A. cepa*. The order of flower opening in the umbel is regular; opening starts with the top or central flowers and progresses uniformly to the umbel base (Pl. 8(*a*)). This striking characteristic will distinguish the Japanese bunching onion from all other cultivated species except the chive, and from the quite similar *cepa-fistulosum* hybrids such as 'Beltsville Bunching', where flower opening is irregular.

HORTICULTURAL GROUPS

Like other onion species which have been under cultivation since prehistoric times, the Japanese bunching onion has many cultivated forms. A number of these have been described as botanical varieties (Prokhanov, 1930; Helm, 1956).

Prokhanov believed that the bunching onion first introduced into Europe and known to Linnaeus was a mat-forming plant with bright green, declining leaves and red-yellow bulb-coats. In contrast to this plant, most of the forms of the bunching onion in China and Japan have inflated, rigid, bluish leaves and white bulb-coats. Prokhanov grouped these latter types under the subdivision Bouddhae. This name is derived from *Allium bouddhae*, a plant which was thought to be typical of the group and was described by O. Debeaux in 1878. More recently, Araki (1950) has revived the name *A. bouddhae* and placed under it most of the previously-described varieties, leaving only a form with nonevergreen leaves and dormant bulbs in *A. fistulosum* L. If *A. fistulosum* were restricted in this way, few of the cultivated forms of the Japanese bunching onion would remain within it.

Certainly we have here a complex systematic problem which can be resolved only by a thorough study of the bunching onion cultivars and such possibly related forms as *Allium altaicum*, *A. microbulbum* (which Prokhanov believed arose from hybridization between *A. fistulosum* and *A. altaicum*), and *A. wakegi* Araki.

Until further studies are made, it would seem reasonable to use the name *A. fistulosum* in a broad sense—i.e. to include material separated from *A. fistulosum* as *A. bouddhae* O.Deb. by Araki—and, as an aid to identification, to maintain as carefully as possible the Chinese and Japanese cultivar names.

While horticultural group names could be suggested on the basis of the described botanical varieties (*fistulosum*, *giganteum*, *viviparum*, and *caespitosum*), the present authors hesitate to do this because of their limited acquaintance with the many east-Asian forms in cultivation.

COMMON CHIVE (SCHNITTLAUCH, CIBOULETTE), *Allium schoenoprasum* L.

Our word 'chive' is derived, through the French, from the Latin *cepa*, i.e. onion, and the word *schoenoprasum* refers to the chive's rush-like leaves.

The chive is known as a wild plant in North America from Newfoundland to Alaska in the north, whence it ranges southwards to New York, Minnesota, and southern Oregon, and, in the Rocky Mountains, to northern Colorado (Ownbey, 1950). In the Old World it is circumpolar in distribution, extending from the far north to Japan, China, northern India, Iran, through the Balkans, and to northern Italy and the Pyrenees. No other onion has so wide a distribution, and few species are more variable.

Levan (1936–37), in a detailed study of the polymorphism and cytology of the chive, notes that the continuous nature of the variation in this species has given rise to great difficulties in its classification, both at the species and subspecies levels. Both diploid and tetraploid forms occur, but, according to the data of Levan, these are not characteristic of the botanical varieties as suggested by Helm (1956). Domestication appears to have wrought no great changes in the chive, and the garden forms, like those in the wild, are extremely varied. As the source of garden forms is usually unknown and hybridization may take place under garden conditions, there seems to be little point in trying to associate our cultivated chives with named wild forms, or to group them in any systematic fashion. Helm listed several cultivars with German names, but named sorts are uncommon or unknown in the United States.

Despite its variability, the chive is easily distinguished among our garden Alliums by its flowers (Fig. 3), its growth in dense clumps, its narrow fistulose leaves, and its lack of well-formed bulbs (Pl. 8(*b*)).

The purple or rarely white flowers, which are borne upright on relatively short pedicels, open first at the top of the umbel and then successively towards its base as the inflorescence matures. Among our vegetable onions, it shares this characteristic only with the Japanese bunching onion. The short, unbeaked spathe remains attached to the base of the inflorescence after flowering; the scape is thin-walled and fistulose, resembling the leaves.

The free-flowering character of most garden forms of chives, and their quite slender leaves, distinguish them from even the smallest of any similar forms of *A. cepa* and *A. fistulosum*. Chive foliage resembles that of the rather uncommon *A. chinense*, but the leaves of the latter are rather sharp-angled, and its well-developed bulbs distinguish it at once.

RAKKYO OR CH'IAO T'OU, *Allium chinense* G.DON

Allium chinense, known to the Japanese as 'rakkyo' and to the Chinese as 'ch'iao t'ou,' is a vegetable onion which is native to central and eastern China and has been spread by cultivation to much of eastern Asia. It is grown to a limited extent in California, and probably as a home-garden vegetable by Japanese and Chinese people in many other parts of the world. No botanical varieties of the plant have been described.

The bulbs of rakkyo divide rapidly, so that it forms clumps, as do chives; moreover, the similarity is enhanced by its narrow, hollow leaves, which, however, are more sharply angled than in the case of chives. Rakkyo has well-developed bulbs, whereas chives never do (Pl. 9(*a*), and cf. Pl. 8(*b*)). In midsummer the leaves die down, and the flowers do not appear until a new crop of foliage emerges in late summer or early autumn. The flower-stalks which emerge in the autumn come from the centre of the old leaves, so that the new leaves, which emerge with the flowers, are lateral to the old ones, and their bases do not ensheath the scape. This arrangement of the leaves and scapes does not commonly occur in the other cultivated Alliums.

The scape of rakkyo is solid and smoothly oval in cross-section; among the cultivated Alliums, only rakkyo has hollow leaves and solid scapes (Fig. 3). The somewhat nodding, purple flowers open in an irregular order over the umbel surface and are quite distinctive in form (Fig. 3). The spathe is persistent. The bulbs are composed of the concentric sheaths of the foliage leaf-bases, so that in cross-section they resemble the bulb of the common onion. The outer bulb scales are thin and dry, and white or grey in colour.

Multiplication is by vegetative means, as most cultivated forms are tetraploids that do not set seed (Kurita, 1952). Several cultivars are known (Chapter XIX). For a review of the botanical history and systematics of this species, usually referred to in the literature as *A. bakeri* Rgl., *see* Mann & Stearn (1960).

CHINESE CHIVES (KUI TS'AI, NIRA), *Allium tuberosum* ROTTLER EX SPRENGEL

Chinese chives or 'kui ts'ai' is a plant that has long been raised in eastern Asia for its edible leaves and young inflorescences. Its common name, 'chive', was undoubtedly applied because, like the chive of Europe, only its tops are eaten. Actually it scarcely forms bulbs at all, its reserves being stored in well-developed rhizomes; it is probably to these that the name *tuberosum* (swollen or enlarged) refers. Its common name in Chinese is *kui ts'ai*, and, in Japanese, *nira.*

The Chinese chive is known both as a wild and as a cultivated plant, but, as it is a plant which easily escapes from gardens, it is now difficult to be certain of its original home. It ranges over much of eastern Asia, from eastern Mongolia to Japan, southwards to the Philippines, and westwards through Thailand to northern India (Stearn, 1946*a*). It is common in botanic gardens, and is one of the best of the flower-garden Alliums. As a home-garden or market-garden food plant, it is much used by the Chinese. Material which we have observed in botanic gardens, grown at Davis, or seen in Chinese markets in San Francisco, appears to be quite uniform except for variations in leaf width (Chapter XIX). No botanical varieties have been described.

As the Chinese chive spreads by rhizomes, it usually forms dense clumps. These clumps, together with the long grass-like leaves bending downwards at the tip, and the still longer and very erect flower-stalks, give it a quite distinctive appearance (Pl. 9(*b*)). The rhizomes may be branched, and are covered with a pale-brown fibrous reticulum—the remains of the old foliage leaf-bases. The scape is solid and has two or more sharp angles running along its whole length. The white, widely-opened, starlike flowers (Fig. 3) are borne in a flat-topped umbel, the short spathe being persistent at its base. The perianth segments of the fragrant flowers have a green line on the outside. The leaves, usually about 5 mm. wide, are flattish above, slightly keeled below, solid in cross-section, and lack a ligule. Their blades are not folded lengthwise as are those of garlic and leek.

The Latin names associated with Chinese chives have long been confused in botanical literature. The plant was called *A. chinense* G.Don by Prokhanov (1930), and has been commonly (but erroneously) united with a related species, *A. ramosum* L., under the name *A. odorum* L. The synonomy and related species have been discussed in an excellent article by Stearn (1946*a*).

SPECIES HYBRIDS

Several species-hybrid cultivars derived from *A. cepa-fistulosum* crosses have been introduced to the trade (*see* Chapters VI, XI). To one familiar with the parent species, these hybrids are easily recognized, by the flowers and inflorescences, as intermediates (*see* Chapter VI for details).

Hybrids between *A. cepa* and *A. fistulosum* continue to be made. Other species have also been crossed with *A. cepa*, and in the future we may expect these sources to contribute more to the *A. cepa*-type cultivars than hitherto.

Photo Dessert Seed Co., Inc.

(*a*) An early white hybrid onion. This onion, adapted to winter production in warm climates, illustrates the uniformity which can be attained in hybrid cultivars.

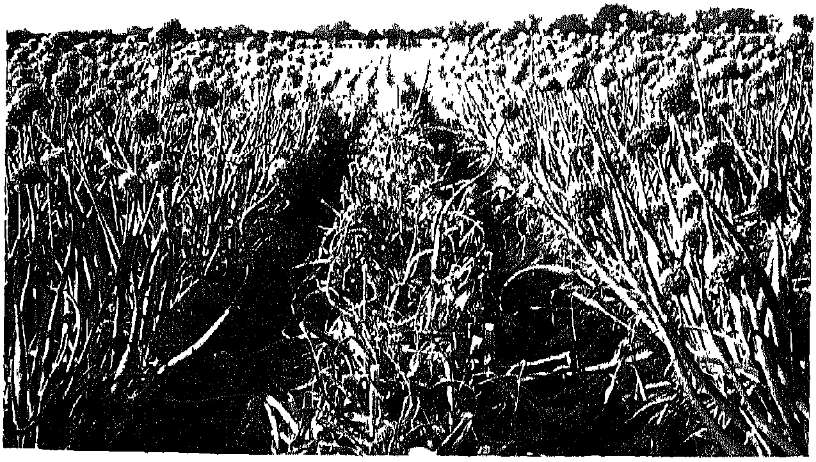
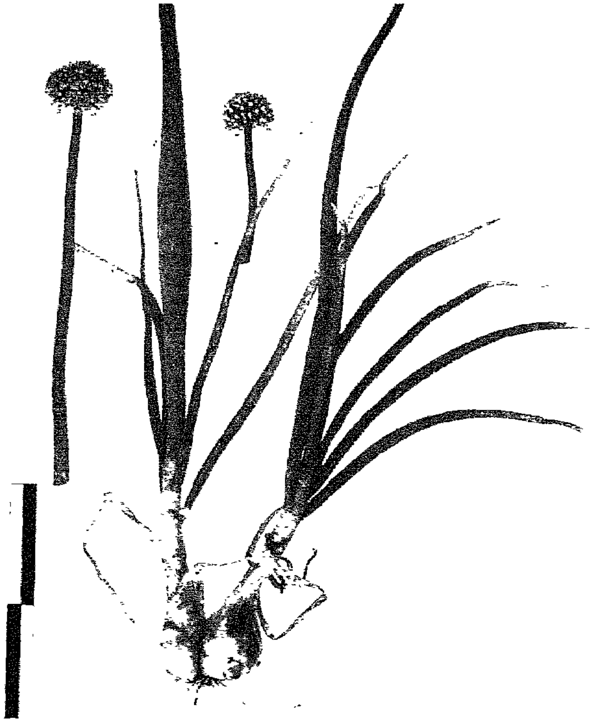


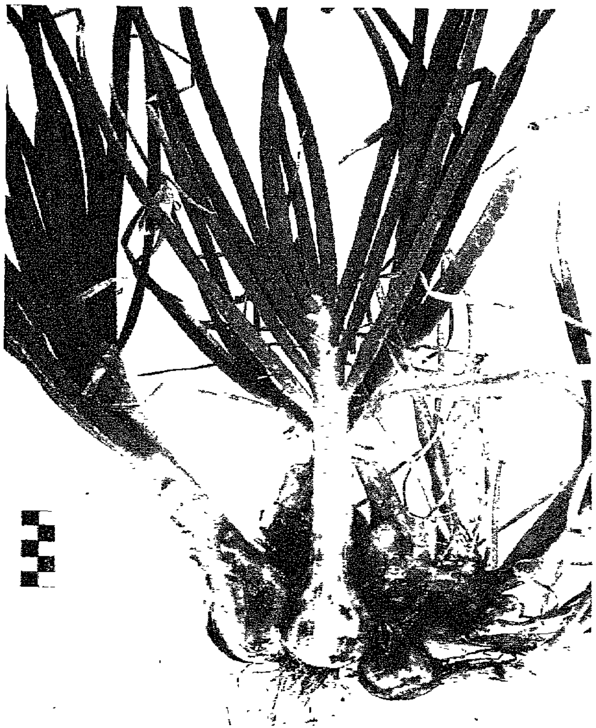
Photo Calif. Agric. Exp. Sta.

(*b*) Seed-stalk production of 'Ebenezer' onions from bulbs stored at different temperatures. *Centre row*, mother bulbs stored at 30°C.; *right row*, mother bulbs stored in open warehouse; *left row*, mother bulbs stored at 12°C. Note how 30°C. storage inhibits seed-stalk formation (H. A. Jones & Emsweller, 1939).

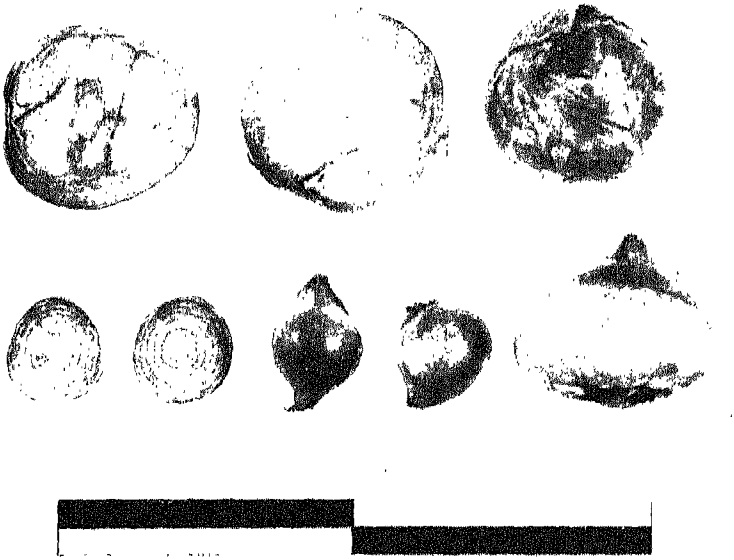
PLATE 2



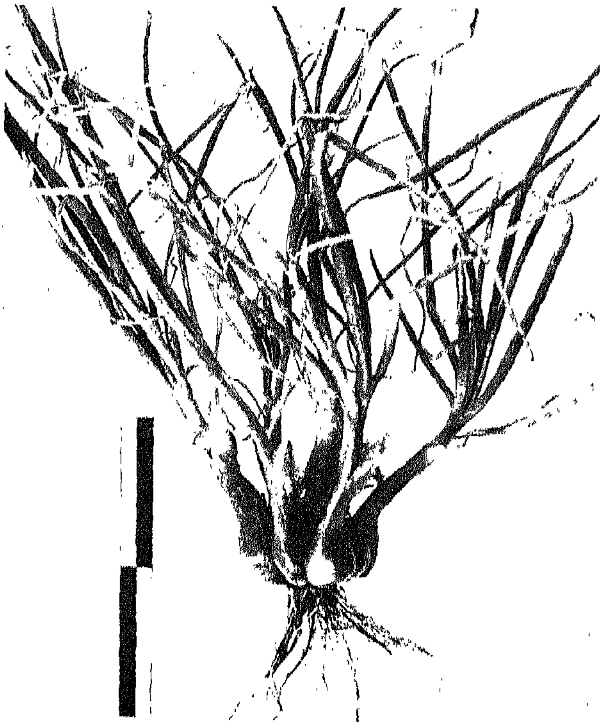
(*a*) The common onion, *Allium cepa* L. (Common Onion group), cultivar Yellow Globe Danvers. The large size of the plant, its well-developed bulbs, and fistulose leaves and scapes—these last conspicuously swollen below the middle—characterize *A. cepa*. The globular umbel and short persistent spathe are characteristic. Propagation is by seed. Scale units = 10 cm.



(*b*) The potato or multiplier onion, *Allium cepa* L. Aggregatum group) This onion is characterized by a large, oblate bulb—usually broader than high (*see* Pl. 4(*a*))—which gives rise to a number of smaller bulbs after a season's growth. These smaller bulbs, in turn, produce the large bulbs. Potato onions may flower, and have been crossed with Common Onion group cultivars Scale units = 1 cm.

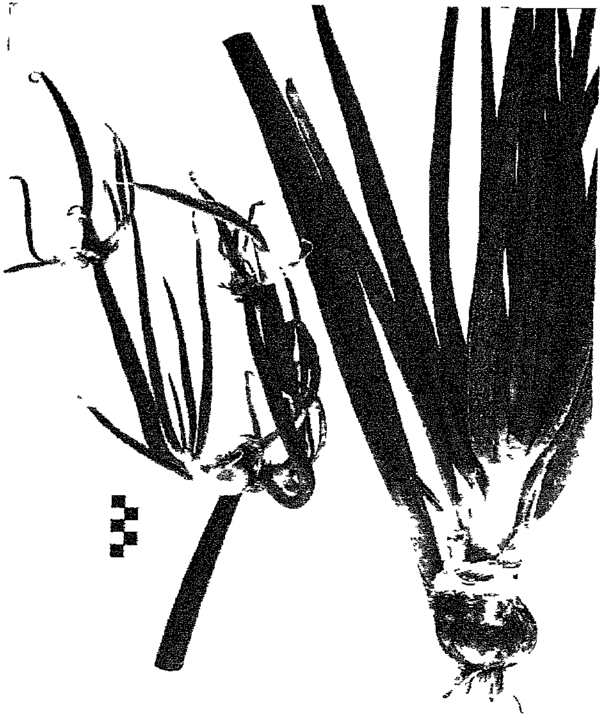


(*a*) Bulbs of the potato or multiplier onion, *Allium cepa* L. (Aggregatum group). The many lateral bulbs within the large bulbs are characteristic of the potato onion. The smaller bulbs are used for propagation. Scale units 10 cm.

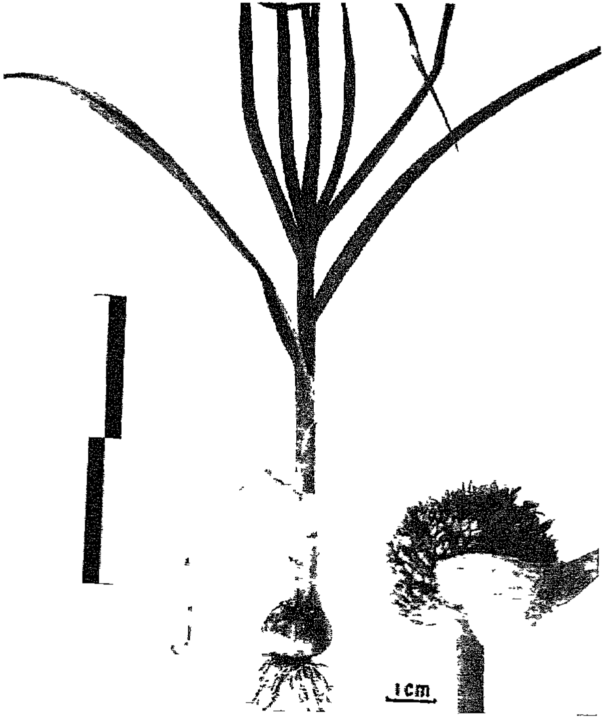


(*b*) The shallot, *Allium cepa* L. (Aggregatum group). The name shallot is applied to forms which produce a cluster of bulbs from a single small bulb during a season's growth. Both bolting and non-bolting kinds are known. True seed may form, but plants are usually propagated vegetatively. Scale units 10 cm.

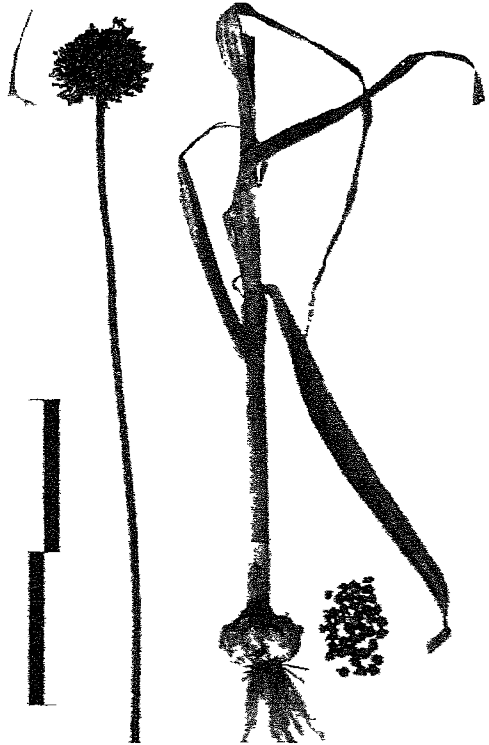
PLATE 4



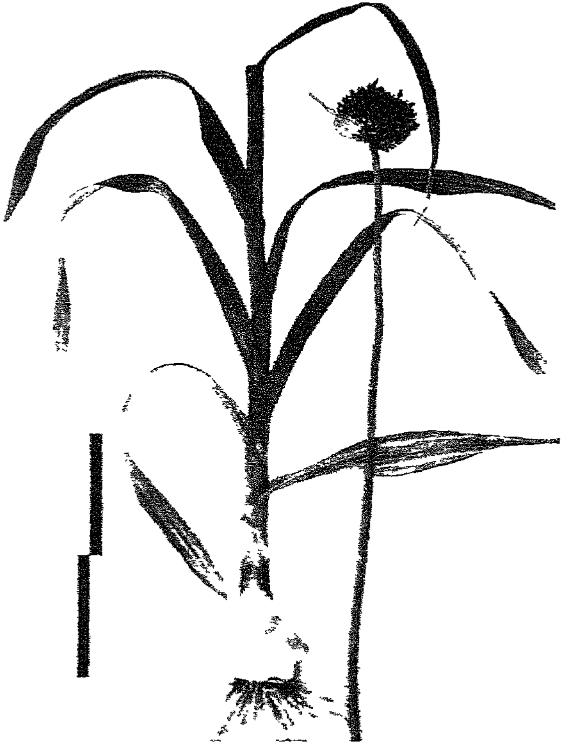
(*a*) The top onion, *Allium cepa* L (Proliferum group) The inflorescence of the top onion may bear bulbs and flowers, or bulbs only The bulbs may sprout on the plant, producing either leaves or leaves and scapes, the latter bearing more top-sets The top onion is reproduced vegetatively from the top-sets
Scale units = 1 cm



(*b*) Garlic, *Allium sativum* L Garlic has flat, longitudinally-folded leaf-blades, as does *A ampeloprasum*, but lacks the exterior bulblets of the latter (cf Pl 6(*a*)) Note the coiled scape and long-beaked spathe Scale units = 10 cm



(a) A wild clone of A[illegible] Greece. This clone set no seed and [illegible] lets. The bulb cons[illegible] many tiny bulblets. The [illegible]



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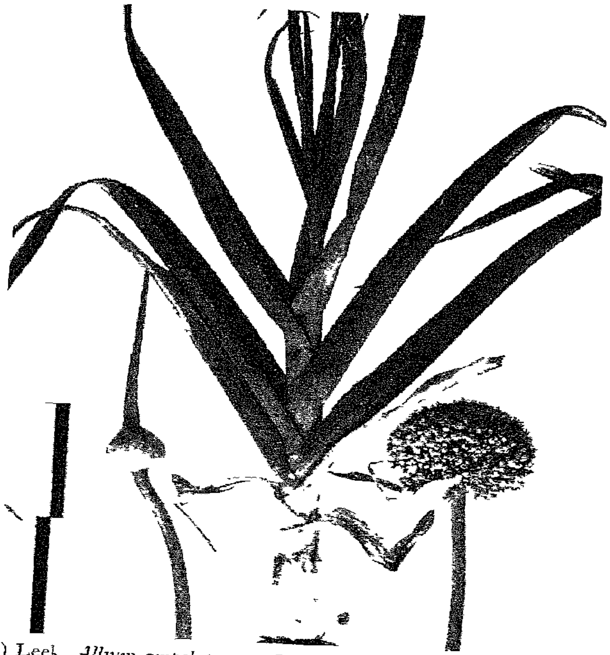
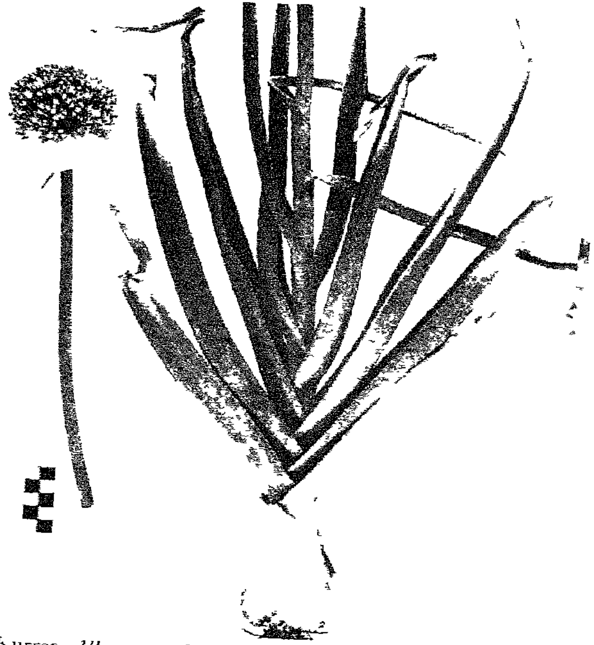
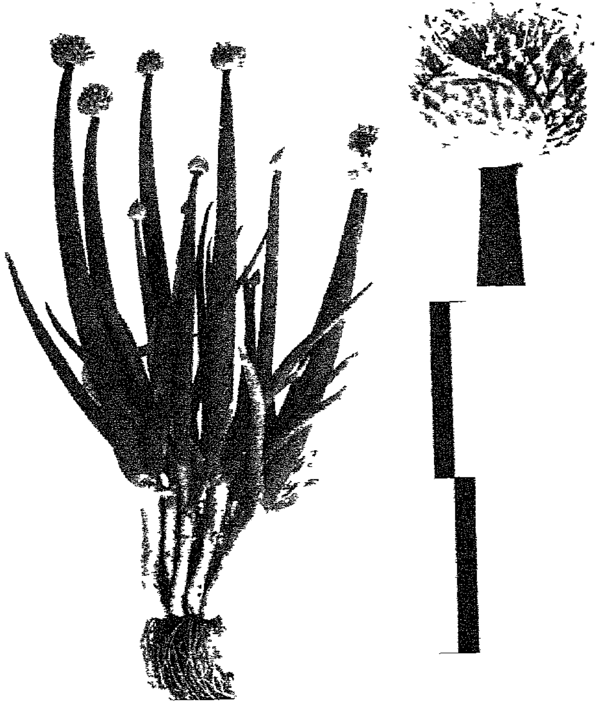


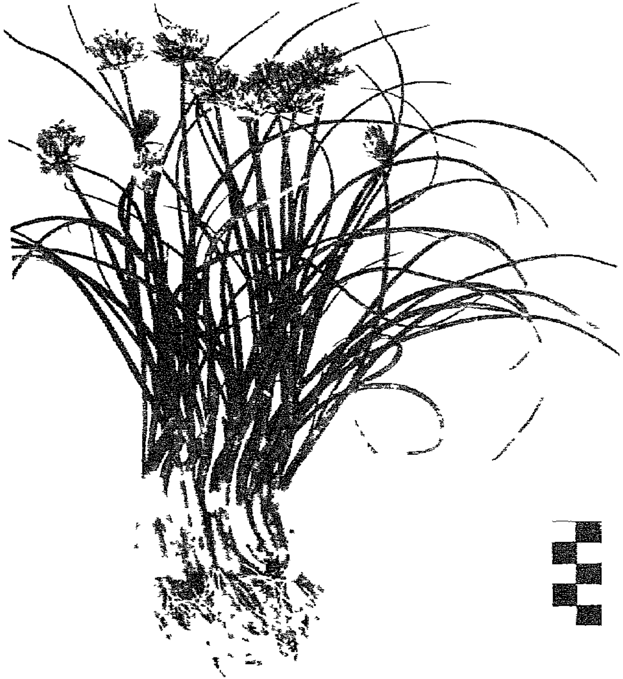
(*a*) Leek, *Allium ampeloprasum* L (Leek group) cultivar Giant Musselburg The thin, folded leaves robust habit and lack of any well developed bulb, characterize the leek Note the small bulblet at the right of the bulb base, similar to those in wild *A ampeloprasum* (Pl 6(*a*)) and great-headed garlic (Pl 6(*b*)) At maturity, Giant Musselburg' usually possesses two large cloves but the extent of bulbing and lateral shoot development in leeks is very variable Scale units = 10 cm



(*b*) Kurrat, *Allium ampeloprasum* L (Kurrat group) Kurrat might be considered as a small-statured leek It has a poorly-developed bulb like the leek and much narrower leaves It is a seed propagated cultivated plant of the eastern Mediterranean region grown exclusively for its tops Scale units = 1 cm



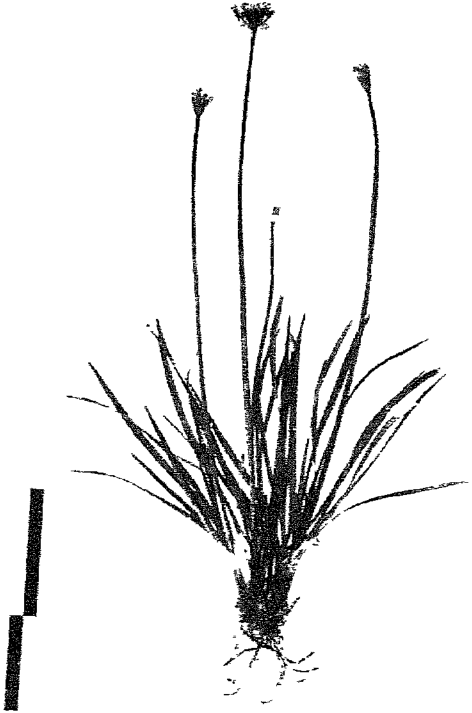
(*a*) The Japanese bunching onion, *Allium fistolusum* L. This variable species resembles the common onion, but differs in lacking well-developed bulbs and in having almost perfectly cylindrical leaves—those of *A. cepa* are flattened on the upper surface. The scape does not have a localized swelling below the middle, as does the scape of *A. cepa*. The umbels (insert) and flowers are also distinct from those of *A. cepa* (Pl. 3(*a*), Fig. 3). Scale units = 10 cm.



(*b*) The chive, *Allium schoenoprasum* L., undergoes rapid vegetative multiplication, so that it quickly forms dense clumps. It is easily identified by its small stature, hollow leaves and scapes, and lack of well-formed bulbs. Its foliage resembles that of rakkyo (Pl. 9(*a*)), but the leaves are less sharply angular in cross-section, as indicated in Fig. 3. Scale units = 1 cm.

PLATE 8

(*a*) Rakkyo or ch'iao t'ou, *Allium chinense* G. Don. Rakkyo is a little-known vegetable that is, however, grown extensively by the Chinese and Japanese for pickling. Plantings of rakkyo look much like chives (Pl. 8(*b*)), but rakkyo has well-formed bulbs. It is summer-dormant and flowers in autumn. Scale units = 10 cm.



(*b*) Chinese chives, *Allium tuberosum* Rottler ex Sprengel. Like rakkyo (Pl. 9(*a*)), this species is used mostly by the Chinese and Japanese people, who eat its leaves and young flowers. Its grass-like leaves, flat-topped white umbels, and well-developed rhizomes (Pl. 14) are characteristic. Scale units = 10 cm.

PLATE 9

IV

MORPHOLOGY AND DEVELOPMENT

THE growth and development of any plant is an interesting phenomenon. The more we know about a plant or crop, the more we tend to be attracted to it. So it is with the onion. Watching the seed sprout, the seedling unfold, the plant grow, and the parts differentiate into highly specialized organs, until seeds are formed again, is a fascinating experience. With onions we soon observe that the patterns of organ formation and development vary not only among different species, but also that, within one species, they depend upon the conditions under which the plant is grown. Thus seasonal changes in day-length and temperature often express themselves in organ formation and growth: seeds from the same packet, planted at different times of the year, may give us scallions, sets, large bulbs, or bolting plants. To understand these differences we must understand how the onion plant develops. Meaningful descriptions of diseases and growth defects also depend upon an understanding of the growth process of healthy plants; and, in present-day agriculture, where cultural practices such as fertilizer placement and irrigation may be easily regulated, a knowledge of such morphological features as root distribution and root growth-rates may be of great importance.

We shall first describe the development of the common onion, *Allium cepa*, because it is familiar to most readers and we know most about it. Other species will then be dealt with by describing the ways in which they differ from *A. cepa.* The internal anatomy of the onion plant will not be dealt with here, as it has been well covered in the excellent reviews of Hayward (1938) and Hector (1938). The work of Kirchner *et al.* (1912–13) deserves the special attention of those interested in morphology. All the species considered here, except *A. chinense* and *A. tuberosum*, are examined in some detail in this work of Kirchner *et al.*, and their references, along with those of Buxbaum (1937), provide a remarkably thorough coverage of the older morphological literature.

THE COMMON ONION

SEED AND SEEDLING

There are several excellent descriptions of seedling development in the common onion: that of Sachs (1863), who was especially interested in seedling food reserves; that of Anderson (1921), with reference to infection by onion smut; that of Hoffman (1933), who described in detail the internal anatomy; and, more recently, the general description by Troll (1954).

The onion seed, fairly smooth and plump while maturing, loses water and becomes wrinkled and irregular in shape as the containing capsules dry. Within the black seed-coat, the embryo, some 6 mm. long by 0·4 mm. in diameter, may be crescent-shaped, or curved into more than a complete circle (Hoffman, 1933). The embryo, which makes up approximately $\frac{1}{10}$ of the bulk of the seed, lies embedded in a tough, thick-walled endosperm—a food tissue containing reserves of carbohydrate, protein, and fat (Sachs, 1863; Cooley, 1895). Most of the length of the embryo is occupied by the cotyledon (Fig. 4(A, B)), which consists of a short, tubular, basal sheath and a much longer blade. The sheath is attached to the short stem of the embryo, and near the apex of the latter (within the base of the cotyledonary sheath) is the primordium of the first foliage leaf of the seedling. The very short primary root, attached to the stem opposite the cotyledon, forms the remainder of the embryo.

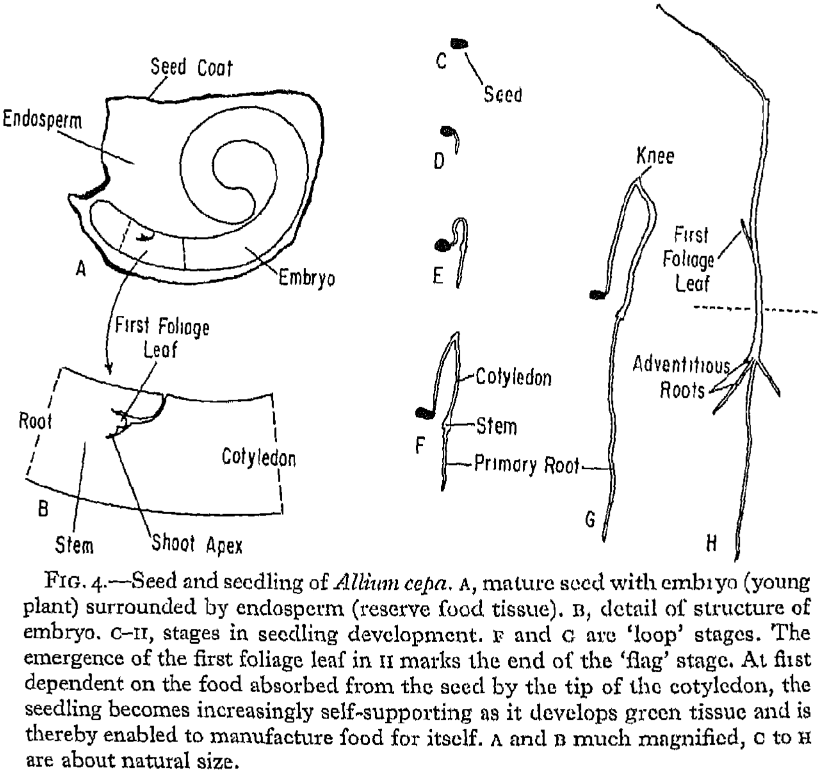


FIG. 4.—Seed and seedling of *Allium cepa*. A, mature seed with embryo (young plant) surrounded by endosperm (reserve food tissue). B, detail of structure of embryo. C–H, stages in seedling development. F and G are 'loop' stages. The emergence of the first foliage leaf in H marks the end of the 'flag' stage. At first dependent on the food absorbed from the seed by the tip of the cotyledon, the seedling becomes increasingly self-supporting as it develops green tissue and is thereby enabled to manufacture food for itself. A and B much magnified, C to H are about natural size.

On germination, elongation of the base of the cotyledon forces the root and stem of the embryo out of the seed-coat, the cotyledonary tip remaining in the seed, where it absorbs the digested food reserve of the endosperm. As the primary root begins its growth downwards, the cotyledon continues to elongate and forms a sharp bend, the knee, which pushes upwards through the soil surface. As it emerges into the light, the cotyledon becomes green and, by carrying on photosynthesis, serves further to supply the seedling with food. After the knee has reached a height of 2 to 3 in., elongation of that part of the cotyledon between the knee and the seed ceases, while the segment between the knee and the stem continues to elongate, pulling the tip of the cotyledon free from the soil (Fig. 4(G, H)). By unbending at the knee, the cotyledon becomes almost erect.

While the cotyledon has been unfolding, the primary root has grown downwards, anchoring the seedling in the soil and supplying it with water and nutrients. By the time the cotyledon has become erect, one or more adventitious roots have usually arisen from the base of the short stem. Since germination began, the first foliage leaf has been elongating within the tubular sheath of the cotyledon, and its blade soon protrudes from the opening at the top of the cotyledonary sheath (Fig. 4(H)). The young plant is now established, and continues to grow by the addition of new leaves from the stem apex and of new adventitious roots from the sides of the stem.

Chemicals are frequently applied to field-grown seedlings at stages of seedling development that are designated by such terms as 'loop stage' and 'flag stage.' Fig. 4(F, G), are typical loop stages. In the flag stage the cotyledon tip has freed itself from the soil, but the first foliage leaf has not yet appeared. The seedling in Fig. 4(H) is at the end of the flag stage and at the beginning of the first foliage-leaf stage.

GROWTH OF THE YOUNG PLANT

After the seedling is established, the young onion plant continues to produce new foliage leaves and adventitious roots, and its short stem slowly elongates and broadens. This pattern of growth, which will be described for the common onion, is essentially the same in all of our cultivated species, and must be clearly understood if one is to appreciate the later changes of bulbing and flowering.

Fig. 5 shows diagrammatically the arrangement of the stem, roots, and leaves of a young onion plant. The position of the primary root of the seedling is indicated, and immediately above it is the part of the stem which was present in the seedling. No part of the stem, once formed, increases in diameter, but as the stem grows upwards, it also broadens and thus assumes the shape of an inverted, solid cone (cf. Pl. 12(*b*), where this shape is well shown in the stem of kurrat). Commonly, as the stem continues to grow upwards, its oldest part—i.e. the stem which served the seedling and young plant—decays, so that the lower surface of the stem is flat (cf. Pl. 11(*b*) at A, of *A. cepa*).

At the centre of the broad stem, on its upper surface, is the apex where new leaves are formed. Each leaf, as first visible under a microscope, arises from the stem tip as a ring, which is somewhat higher on one side. This ring, as it grows upwards, forms a tube (the sheathing leaf-base), and the high side of the ring elongates into the leaf-blade. The shoot apex is thus left within, and at the bottom of, the youngest tubular leaf (Fig. 5). In time, the apex gives rise to the next leaf, so that each leaf surrounds the successively younger leaves which follow it. As indicated by the arrows in Fig. 5, the top of the stem expands outwards as well as upwards, so that the space within the circular leaf-bases continually enlarges, providing room for the new leaves which are forming.

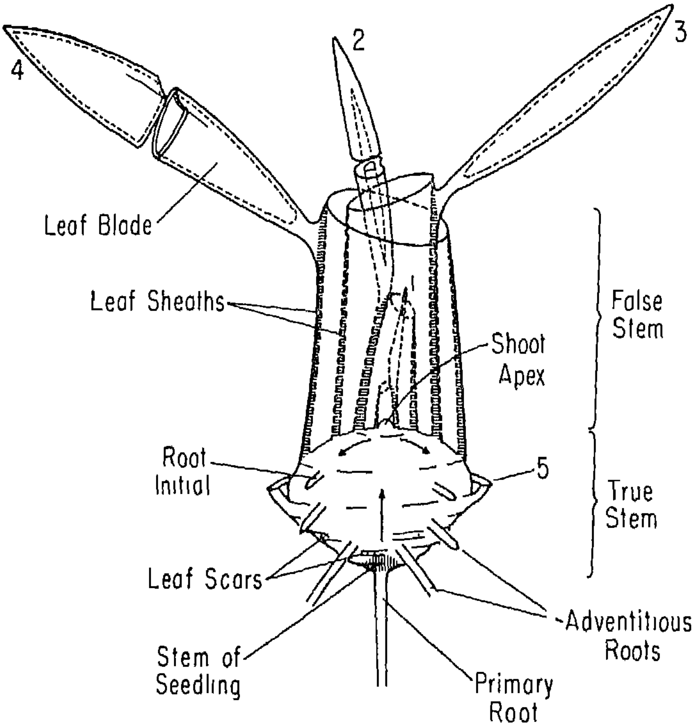


FIG. 5.—A diagrammatic picture of the development of the stem, leaves, and roots, in a young plant of the common onion. Each new leaf arises at the stem or shoot apex, leaf 1 being the youngest and leaf 4 the oldest of the four leaves shown. Each leaf arises as a ring of tissue which grows upwards as a tubular sheath. The leaf-blade elongates from one side of the sheath's top. As the stem grows upwards, it also broadens, as is shown by the divergent arrows in the diagram. New roots continually arise in the younger (upper) part of the stem. In this figure, the space between adjacent leaf-sheaths is much exaggerated.

The leaves alternate in position along the stem; i.e. each leaf-blade extends from the side of the plant opposite (180° from) the leaf-blade which preceded it, so that the leaves are disposed in two ranks (Fig. 5).

The leaf-sheaths which project above the ground, and to which the leaf-blades are attached, form a firm structure which is commonly called a stem, but which, more properly, should be called a *false stem*, to distinguish it from the true stem at the plant's base (Fig. 5). Only when a seed-stalk is formed, does the true stem elongate and extend well above the other parts of the plant.

While the leaf-sheath, a hollow tube open at the top, gets its form by growing upwards from a ring-like initial, the leaf-blade, also hollow, but completely closed (Fig. 5), develops in a quite different way. The young leaf-blade is solid, and as it enlarges, the central tissues fail to grow as rapidly as the surface tissues; this, along with some cell destruction, causes a large cavity to form within. The hollow inflorescence-stem develops in the same way.

Onion roots increase little in diameter, once they are formed, and for this reason new roots must continually arise from the stem if the enlarging top of the plant is to be adequately supplied with water and nutrients. These new roots never arise among the old roots, but always from the younger stem tissue—i.e., at higher levels on the short, vertical stem—frequently pushing out through the bases of the older leaves.

Almost all of the cultivated onions produce lateral branches at some time during their growth (Pl. 11(*b*)). These short-stemmed branches arise as buds in the leaf axils, i.e. within and at the base of a sheath, and always on the same side of the sheath that bears the leaf-blade. In garlic, several buds may arise side by side in the axil of one leaf (Pl. 12(*a*) at B), but in most of the cultivated onions buds arise singly.

The inflorescence axis or seed-stalk (also called the 'scape') always arises at the apex of the stem (Pl. 12(*b*)). When the inflorescence forms, further leaf production by this particular axis ceases, but growth is usually continued by lateral branches. As shown in Pl. 13(*b*), the vigorous growth of a lateral bud may sometimes make the inflorescence appear as if it arose from the side of the stem.

ROOTS

Since Goff (1887) first described onion root systems as extending 16 to 18 in. deep and no more than a foot laterally from the bulb, a number of workers have confirmed the fact that the onion has one of the most limited root systems among the vegetable crops. Thompson (1921) noted that few roots of transplanted onions reached a depth of more than 10 in., and that, while the greatest lateral extent was 12 in., very few reached more than 6 in., the main root system being found within a radius of 6 in. of the bulb.

The most extensive observations on onion roots have been made by

Weaver & Bruner (1927). These authors noted that an individual plant may have from 20 to 200 roots, varying individually from 0·5 to 2·0 mm. in diameter. Commonly, 3 to 5 branch-roots arise along each inch of the adventitious roots, but these laterals rarely rebranch. In a large plant, the roots spread horizontally from the bulb base for 12 to 18 in. and then grow downwards to depths of 18 to 32 in., but the bulk of the roots are in the upper 1 to 2 ft of soil. In heavy or compacted soils the root system may be more sparse. Not only is the onion root system very limited in its spread and depth as compared with that of many other plants, but it fills the soil poorly, because of its sparse branching. The drawing of onion root distribution by Drinkwater & Janes (1955) agrees well with these conclusions of Weaver & Bruner. Goff (1887) reported root-hairs on roots growing into open spaces beneath the soil surface, but found none on roots in the soil; and Rimbach (1924) believed them to be commonly lacking. While Rimbach did not record the total extent of onion root systems, he noted that roots reached lengths of 30 to 50 cm. and grew at rates of about 1 cm. per 24 hours.

Newly formed roots may almost always be found on actively growing plants, and older roots may die as the plant ages. Sideris (1925) claimed that, at the time of germination, onions produced a first set of roots, which gradually died, and then, at the time of bulbing, they produced a second set, which functioned until the plant matured. No later workers appear to have confirmed this. In our own field observations (*see* below), 'Excel' seedlings had an average of three roots on March 30th, 27 days after planting. The primary root was still active and differed little in size from the adventitious roots. New roots were added at a uniform rate of 7 or 8 every 2 weeks until May 26th (well after bulbing had started), when each plant had some 35 roots—the maximum number observed. As the plants matured in June, the roots died more rapidly than they were produced, and at the time of harvest, when the soil was quite dry, each plant had an average of 19 living roots. There was no evidence of two main periods of root production.

The fact that individual onion roots are limited in size, and that new adventitious roots must be added to the root system as the plant top enlarges, has been discussed above. What is of considerable importance to the onion grower in this connection is that new roots cannot grow out into dry soil. Soil moisture must reach the bulb base at least periodically during the growing season to permit elongation of the new roots. Jones & Rosa (1928) show a striking photograph of onion plants with 3 to 5 leaves but only a single root each (the primary root). These plants had been grown, since seed germination, in a soil with a dry surface layer. Within 2 days after the bulbs observed by Jones & Rosa were watered, numerous new roots were protruding from all the bulbs.

The stems of most bulbous and

they were not moved downwards by contractile roots. Rimbach (1924) studied contractile roots in several cultivated onions, noting that they were essentially inactive in *Allium cepa*, but quite effective in garlic and leek. He calculated that leek bulbs could be moved downwards as much as 1 cm. in 1 month. Little attention has been paid to contractile roots in cultivated plants, but their possible importance should be considered in depth-of-planting and similar studies. An excellent account of such movements in plants, including observations on a number of *Allium* species, is given by Galil (1961).

BULB FORMATION

When conditions of day-length and temperature favour bulbing in the onion, a series of changes is initiated, the most characteristic of which is the enlargement of the leaf-bases a short distance above the stem, and the storage in these of reserve food. Less conspicuous are the changes in form of the new leaves which are being produced in the bulb centre, the production of lateral buds, and, finally, the cessation of root production and the entry of the entire plant into a state of rest.

While there are many descriptions of seedling development in the onion, few papers have appeared on bulb development. Irmisch (1850), Kirchner *et al.* (1912–13), Hoffman (1933), Rauh (1950), Troll (1954), and others have given very general descriptions. Only the papers of Heath & Holdsworth (1948, and references cited therein) on onion sets, and those of Aoba (1954, 1956) on large bulbs, give detailed accounts of bulb development. In the following description, based mainly on an early spring planting of 'Excel' bulbs grown at Davis, California, the sequence of changes from seedling growth through bulbing and maturity is briefly summarized. These onions were seeded into the field on March 3, and harvested when the tops of about half of the plants were down—on June 22nd, which was 111 days later. The plants grew under a regimen of increasing temperatures and day-lengths, and at maturity the bulbs averaged about 5 cm. (2 in.) in diameter. Ten plants were first dissected under a microscope on March 30th, and thereafter similar samples were examined at two-week intervals until harvest. Plants from three of the harvest dates are shown in Pl. 10, and a longitudinal slice of a partly-formed bulb is shown in Pl. 11(*a*).

On March 30th, when the cotyledons were erect and about half of the seedlings had their first foliage leaf exserted from the cotyledon, the second foliage leaf was present in all plants and the initial of a third in about half of the plants. From this time until harvest, leaves were initiated at a fairly uniform rate of about one per week, so that, by the time the bulbs were mature, some 15 or 16 leaves had been formed on the main stem.

[illegible] bulb is first brought about by the thickening bulb may consist of these (Pl. 11(*b*) at B). However, as bulbing progresses, leaves near the bulb centre abort their blades and become storage sheaths. While the sheaths of the blade-bearing leaves normally extend well above the top of the bulb, so that only their lower part becomes thickened, the sheaths of leaves with aborted blades do not extend beyond the bulb, and the entire sheath thickens (Pl. 11(*b*) at C).

When the 'Excel' bulbs were mature (June 22nd), the first 3 or 4 leaves produced by the plant had become dry and had disappeared—or persisted only as thin sheathing scales. Within these there were about 7 thickened sheaths, the outer 4 of which were foliage leaf-bases, and the inner 3 were leaves with aborted blades.

Within these thickened storage sheaths, and near the bulb centre, were the last 5 or 6 leaves formed during the growing-season. These young leaves remained small, but protruded as sprouts if conditions following storage became favourable.

In the above account, only those leaves that were borne on the main bulb-stem which arose from the embryo were considered. However, each 'Excel' bulb produced at least one lateral bud. This lateral was located in the axil of one of the innermost blade-bearing leaves, or within one of the outermost bladeless leaves. These buds were initiated when the bulbs first began to enlarge (Pl. 10, B), and in a few of the plants a second, or even a third, lateral bud was found. The outer leaves of the lateral buds may become quite thick—in some 'Excel' bulbs a lateral bud made up as much as one-third of the bulk of the whole bulb—or, alternatively, all leaves of the lateral may remain quite small. In either case, the small central leaves of the lateral buds, like those of the main axis, will grow out later, when the bulb sprouts. Leaves with green blades were never produced on the laterals during the season in which the latter were formed, i.e. the plants had only a single top. This is not always true, however, and in certain cultivars, such as 'Crystal Wax,' bulbs from seed may occasionally produce more than one top. Bolting plants may produce green leafy laterals when the initiation of the seed-stalk stops the production of leaves by the main axis.

Bulb sections of the cultivar Calred (Pl. 11(*b*)) clearly illustrate the position of bladed and bladeless leaves in a mature bulb. In the sectioned bulb at B, a total of seven apices were present (the apex of the primary stem and six laterals). This extensive branching during the first season's growth explains why bulbs produce several tops or several inflorescences during the second year of growth.

Heath & Holdsworth (1948) have noted that little food storage takes place in the foliage leaf-bases of onion sets, but that the bulb consists mostly of a few thickened sheaths of bladeless leaves. Also, lateral buds are usually not formed in sets, so that, during their second season of growth, plants from sets produce bulbs with single tops or, if they flower, with single inflorescences. If sets are large, however, they may contain laterals, as described above for bulbs, and then will produce more than one top or inflorescence the following season.

As bulbs mature, the leaf sheaths weaken just above the bulb and the tops may fall over under their own weight. This weakening of the neck is usually attributed to the fact that the central leaves of the bulb have ceased to elongate into the neck. However, collapse of the neck tissues may also be involved; as yet no careful study of the fall of tops at maturity has been made.

Aoba (1954, 1956) analysed the leaf types in bulbs of four Japanese cultivars. He studied the lengths of all leaves making up the bulbs, and showed how dry, thin, and thickened foliage leaf-bases, as well as bladeless leaves, varied in number and shape as bulbing progressed. Aoba found that, within a cultivar, the number of thickened foliage leaf-bases, and the number of lateral buds and bladeless leaves which they contain, increased with increasing bulb-weight. On the other hand, the number of bladeless leaves surrounding the lateral buds decreased with increasing bulb-weight.

INFLORESCENCE, FLOWERING, AND SEED FORMATION

Like bulbing, flower production is induced by environmental factors (Chapter VIII); when these are favourable, the shoot apex ceases to produce leaf primordia and initiates the inflorescence. The inflorescence consists of from 50 to 2,000 or more flowers enclosed by modified leaves which make up the spathe. When the spathe first forms, it looks much like the primordium of a single foliage leaf; but the internode below the spathe soon starts to elongate and, consequently, the inflorescence is easily recognized when it is yet quite small. The flower-stalk is an apical extension of the stem, and the region between the inflorescence bracts (spathe) and the uppermost foliage leaf is the only internode which elongates during the life of the plant. Like the leaf-blade, the inflorescence stalk of the common onion is at first a solid structure but, through differential growth, becomes thin-walled and hollow as it increases in size.

The number of flower-stalks produced by a single onion plant may vary from one to well over a dozen. As noted above, each inflorescence is produced at the apex of an axis. If bulbs are grown vegetatively for one season and planted for seed production the next year, the apex of the main axis, and the apices of the many lateral buds present, may each develop into an inflorescence. Bolters in plantings grown from seed or from small sets usually bear only a single inflorescence, as the plants have but a single shoot-apex and no lateral buds at the time they are induced to flower. Likewise, plants in seed-crops grown from seed may have fewer inflorescences per plant than those raised from mother bulbs.

As flowering and seed production usually occur during late spring or early summer, bulb formation commonly accompanies flowering. The extent of bulbing under these conditions varies greatly. This is to be expected, as bulbing and flowering are largely responses to separate environmental factors, and because cultivars vary somewhat in their time of flowering and greatly in their time of bulbing. Some lateral, vegetative bulbs are usually formed, and these may be extensive enough to carry the plants over another season, or they may be so poorly developed that further vegetative growth is difficult to maintain.

The inflorescence is an umbel. In most species of onions it is an aggregate of many smaller inflorescences (cymes) of 5 to 10 flowers each. It is quite different in structure from the umbel of such plants as the carrot, and because such genera as *Narcissus* and *Amaryllis* have similar inflorescences, many botanists now place *Allium*, along with these and related genera, in the family Amaryllidaceae.

Within each of the small cymes of the inflorescence, the flowers open in a definite sequence and with a considerable delay between successive flowers. Because the whole inflorescence of the common onion consists of dozens of these smaller inflorescences, the flowers of the umbel appear to open quite irregularly and, as noted by H. A. Jones & Rosa (1928), over a period that may be as long as two weeks or longer. A single plant, producing several inflorescences, may have flowers opening for a month or longer. Chinese chives (*A. tuberosum*) possesses perhaps the simplest inflorescence among the cultivated species, the whole inflorescence commonly consisting of only two cymes of some twenty flowers each.

The flowers (Fig. 3) may be considered to be made up of five whorls of three organs each, which, starting at the centre, are: 3 carpels (united into a single pistil), 3 inner stamens, 3 outer stamens, 3 inner perianth segments, and 3 outer perianth segments. The members of each successive whorl alternate; i.e. they are on different radii from the members of adjacent whorls. The development of these flower parts has been described in some detail by H. A. Jones & Emsweller (1936*a*).

The pistil contains three compartments or locules, each of which encloses two ovules. In each of the septa or walls separating the compartments of the ovary lies a mass of nectary tissue, which opens to the surface by a pore under a flap of tissue on the outer wall of the ovary. As the nectaries are between the carpels of the ovary, they stand opposite to the three inner stamens. These stamens have much broader filaments than the outer stamens—frequently with a tooth on either side of the filament base—and drops of nectar collect between these broad filaments and the ovary wall.

The anthers of the inner stamens shed their pollen first, as do then those of the outer stamens, all of the pollen being shed over a period of two to three days. The style begins elongating slowly when the flower opens, but reaches its full length only after all the pollen has been shed. It is then that the stigma becomes receptive. While this delay in the receptivity of the stigma may reduce self-pollination of single flowers, insects readily transfer pollen among flowers within an umbel and between different plants (Chapter VII).

The ovules in the locules of the ovary are anatropous, i.e. they so bend over during development that the apex of the ovule is near the ovule base or point of attachment. Each ovule develops two outer coverings, the integuments. Within these, in the central tissue of the ovule (nucellus), a cell immediately beneath the epidermis is distinguishable early in its development by its dark-staining cytoplasm and large size. This cell, the megaspore mother-cell, divides once, and the inner of the two daughter cells gives rise to the embryo sac. In many plants the megaspore mother-cell gives rise to four megaspores, three of which disintegrate and one of which forms the embryo sac. The embryo sac of *Allium* is 'bisporic', in the sense that it is derived from a cell which commonly gives rise to two megaspores. By three divisions of the nucleus of this cell, the eight nuclei of the embryo sac are formed. Three of these eight nuclei organize themselves into an 'egg apparatus'—an egg cell and two synergid cells—at one end of the embryo sac, and two, the polar nuclei, remain in the centre of the embryo sac.

Fertilization of the egg by a male nucleus initiates the embryo, and fertilization of the two polar nuclei by a second male nucleus initiates the endosperm tissue which will surround the embryo and largely fill the mature seed. As the seeds mature, the capsule dries and splits from the apex down its centre and down each locule (loculicidal opening), freeing the easily-detached seeds. Further information on fertilization and embryo formation may be found in the accounts of Strassburger (1879), Weber (1929), and H. A. Jones & Emsweller (1936*a*), and in the books of Johansen (1950) and Maheshwari (1950).

OTHER SPECIES

Many features of the common onion, *Allium cepa*—the short internodes of the vegetative plant, the sheathing leaves, the terminal inflorescence, and the continual production of adventitious roots—are common to all of the Alliums which are grown for food. Even the seedlings are so alike that these species are not easily distinguished in the early stages. For this reason, and as *A. cepa* has been described in some detail, the structure of the other cultivated species will be characterized mainly by the ways in which they differ from the common onion.

Allium sativum (GARLIC)

The garlic plant differs from that of *A. cepa* in the following conspicuous ways: (*a*) the leaf-blades are not hollow and inflated, but flat and folded lengthwise, with a keel or angle on the lower surface; (*b*) the scape is solid, not hollow, and small bulbs are always mixed with the flowers of the inflorescence; the flowers usually abort in the bud stage, and although there are reports of seed production in the literature (Kononkov, 1953), confirmation is needed that the garlic ever produces seeds; (*c*) in garlic the foliage leaf-bases never store food as do those of *A. cepa*, but mature as thin, dry scales, the sole storage organs of the bulb being the axillary buds (cloves) of the foliage leaves; and (*d*) at maturity the main stem of the bulb, and the roots and leaves attached to it, all die—only the cloves, which are cut off by an abscission layer, remain to carry the plant on for another season.

The structure of the garlic clove is indicated in Pl. 12(*a*). The clove consists of two mature leaves and a vegetative bud. The outermost of the mature leaves is the *protective leaf*, a cylindrical sheath with a small opening at the top and a minute, aborted blade. This sheath, which surrounds the whole clove, has a surface layer of tough fibres, and becomes thin, dry, and dead at maturity. Within the protective leaf is a single *storage leaf*, a thickened sheath which is the only storage structure of the clove and accounts for almost all of its bulk. Within and at the base of this storage leaf are several very small leaves which form the bud for next year's growth. The outermost leaf of the bud, the *sprout leaf*, lacks a blade and, when the clove sprouts, pushes up through the soil, but grows no farther. From within the sprout leaf arise the foliage leaves which constitute the green top of the plant.

When environmental conditions favour bulb formation in garlic, the cloves are initiated in the axils of the foliage leaves. These buds appear only in the axils of the younger leaves—i.e. leaves near the plant's centre—so that there may be a dozen or so 'sterile' foliage leaves, surrounding the bulb, which have no cloves in their axils, but serve merely as wrapper leaves. Within these wrapper leaves, a series of successive leaves, from 2 or 3 to perhaps 10 or more, bear axillary cloves. The number and arrangement of cloves vary among cultivars; Pl. 12(*a*) shows an arrangement that is typical for 'California Late'. Because of the large number of easily separable cloves, garlic is much better adapted to vegetative propagation than are most types of the common onion.

Garlic cultivars vary greatly in their tendency to bolt, some rarely if ever bolting, others always doing so. Frequently the flower-stalk is very short, so that small clusters of bulbs, the top-sets of the inflorescence, appear within the false stem or even at the very top of the ground bulb.

The root system of garlic, like that of the common onion, is not extensive. Weaver & Bruner (1927) found, for garlic planted on October 1st at Norman, Oklahoma, that by December the root system had spread a maximum of 9 in. from the bulb and had reached a depth of 11 in. When the plants were maturing in June, each had between 40 and 60 roots, which reached a maximum of 18 in. from the bulb and 2·5 ft in depth. The roots were somewhat more branched than those of the onion, and thoroughly occupied the surface soil. Except for this, the root systems of garlic and onion are much alike in all respects.

For further information on the structure of garlic, and for information on its internal anatomy, *see* Mann (1952).

Allium ampeloprasum (LEEK, KURRAT, GREAT-HEADED GARLIC)

This species is closely related to garlic, and the ways in which certain forms, such as great-headed garlic, differ from the common onion, are in general the same as those listed above for garlic. *A. ampeloprasum* differs from garlic in the following ways: it usually produces two distinct sizes of cloves; it rarely forms top-sets; and some forms are fertile. In forms which produce cloves, the small cloves are produced in the outermost leaves—the same leaves which are sterile wrapper leaves in garlic. These small cloves are usually dormant and have thick protective leaves. The larger cloves are produced nearer the bulb centre (Pls. 6(*a*) and (*b*)).

In place of several large cloves, great-headed garlic frequently produces a single, large, symmetrical clove that is commonly referred to as a *round*. A round is terminal on the main stem, and a plant producing a round never bolts. Plants grown from rounds or very large cloves usually produce several cloves and a seed-stalk; plants grown from cloves frequently produce a round. Thus there is a tendency for a plant to produce a round one year and a group of cloves the following year (bolting only every other year), but this alternating pattern is not followed consistently. The internal structure of rounds and large and small cloves is similar, and differs in no important respect from that given above for garlic cloves. Small rounds may be produced by garlic grown under unfavourable conditions, but never generally as in great-headed garlic.

In leek and kurrat, which we believe to be derived from *A. ampeloprasum*, the ability to form lateral bulbs has been lost in varying degrees. Perhaps here some food storage takes place in the foliage leaf-bases, but they never thicken into a conspicuous bulb. In some leeks, both small and large cloves are found, and in the perpetual leek the laterals apparently have little rest and grow out as side shoots, so that clumps of green tops are formed. In the kurrat which we have grown at Davis, no cloves of any kind have been observed, and the plants die after flowering, as no lateral buds are present to continue growth (Pl. 12(*b*)). A detailed comparison of the external morphology of the leek, kurrat, and the F_1 hybrid between them, is presented by Kadry & Kamel (1959). Kirchner *et al.* (1912–13) give an interesting discussion on the morphology of *A. ampeloprasum* and related species.

Weaver & Bruner (1927) describe the root systems of 'Large London' leeks planted at Norman, Oklahoma, in mid-March. After 4 months' growth, the plants had 50 to 100 or more main roots, which spread 14 to 21 in. from the stem and ramified in the soil to a depth of 18 to 24 in. The roots penetrated less deeply than onion roots, but spread farther laterally and occupied the surface soil more thoroughly. On some roots branching occurred irregularly; on others branching occurred almost uniformly, with approximately two branches for each inch of length. The branch roots rarely rebranched. The oldest plants (approximately 4 months) examined by Weaver & Bruner were fairly young for commercial leeks, and these authors observed that the root systems were 'still developing vigorously and would probably have extended much deeper'.

Allium chinense (RAKKYO)

Rakkyo, like *A. cepa*, forms conspicuous bulbs (Pl. 13(*a*)). However, because of its small stature and the rapid multiplication of the bulbs to form clumps, the above-ground parts resemble the common chive. The foliage leaves have sheathing bases and hollow blades as in *A. cepa*, but the very slender scape is solid. The bulbs, unlike those of *A. cepa*, consist of foliage leaf-bases only; storage sheaths with aborted blades are not produced. The bulb is formed from the thickened bases of several foliage leaves which appear as concentric rings in the cross-section of a bulb.

Rakkyo is very unusual among the Alliums in that the leaves die during midsummer when the bulbs would appear to go into a state of rest, and the inflorescence emerges in the autumn (October) along with a new crop of leaves. These new leaves are from lateral buds in the old foliage-leaf axils. Many lateral buds are formed, and during the winter and spring these continue to produce their own tops, so that the old bulb is replaced with a cluster of new bulbs (Pl. 9(*a*)). The number of bulbs produced, and their size, vary greatly among cultivars. The flowers of all cultivars appear to be sterile and, as in garlic, rakkyo is propagated by bulb divisions.

Seasonal studies on the time of initiation of the inflorescence and lateral buds have yet to be made. Information on leaf anatomy is given by Mann & Stearn (1960).

Allium fistulosum (JAPANESE BUNCHING OR WELSH ONION)

The hollow leaf-blades and scape of the Japanese bunching onion resemble, in both size and structure, those of *A. cepa*. This species differs from *A. cepa*, however, in that: (*a*) it has no well-developed bulb (Pls. 8(*a*), 13(*b*)); (*b*) all the leaves are foliage leaves, i.e. no bladeless storage leaves are produced; (*c*) the lateral buds which arise near the shoot apex are neither storage organs nor resting buds, but elongate as tillers, so that the plant develops into a clump with many tops; and (*d*) the flowers, instead of opening irregularly over the surface of the umbel, open first at its apex, and then progressively towards its base (Pl. 8(*a*)).

Allium fistulosum, like *A. cepa*, has many horticultural forms, and these vary strikingly in such features as stature and degree of tillering.

Yakuwa (1953, 1955) has described in some detail the position of lateral buds or tillers in the cultivar Sapporo-Futonegi. Of the species discussed so far, *A. fistulosum* is the first in which the stem is so persistent that a definite rhizome is formed. The rhizomes can best be seen in two-year-old plants, where they extend laterally a short distance from the base of the false stem. They are encircled by the scars of the previous year's leaves, show the attachment points of old scapes, and still bear roots on their younger parts.

Watanabe (1955) noted, for cultivars planted in September, that inflorescence initiation occurred in December (1 cultivar) or mid-January (7 cultivars). Inflorescence and flower development have been described in detail by Eguchi *et al.* (1958). Eguchi *et al.* (1958*a*), working at Hiratsuka, Japan, noted in a 3-year study that the cultivar Senju-Aigara, transplanted in late January or early December (about 8 to 18 months after seeding), produced 2 or 3 inflorescences per plant (range 1 to 5), and that flowering of the first umbels began in early- to mid-April. The first umbel contained from 350 to 400 florets, with smaller numbers in successive umbels—the first 2 umbels producing 90 per cent of the flowers on the plant. Flowers of a single umbel opened over a period of about 20 days, and for individual flowers there was a peak of anther dehiscence between 10.00 a.m. and 2.00 p.m. Eguchi and his colleagues also studied the relation of temperature and humidity to flower opening and anther dehiscence.

Allium schoenoprasum (CHIVES)

Although chives and *A. fistulosum* differ greatly in stature, they are much alike in gross structure and development. How close the relationship is between them is unknown, and hybrids of the two species have not been reported. The contrasts listed above, comparing *A. fistulosum* with *A. cepa* ('*a*' through '*d*'), apply without modification to *A. schoenoprasum* (Pl. 8(*b*)).

Chives are extremely variable, both in the wild state and in cultivation (Levan, 1936–37). All forms of chives appear to tiller very rapidly, so that clumps are quickly formed from single plants or from seedlings. Chive rhizomes are quite small, and the older portions die, so that chive clumps usually consist of many disconnected sections. Flowering occurs in early spring, with a gradual reduction in flower production thereafter. The only morphological works on *A. schoenoprasum* appear to be the study of Schumann (1890) on leaf and inflorescence initiation, and the general description in Kirchner *et al.* (1912–13).

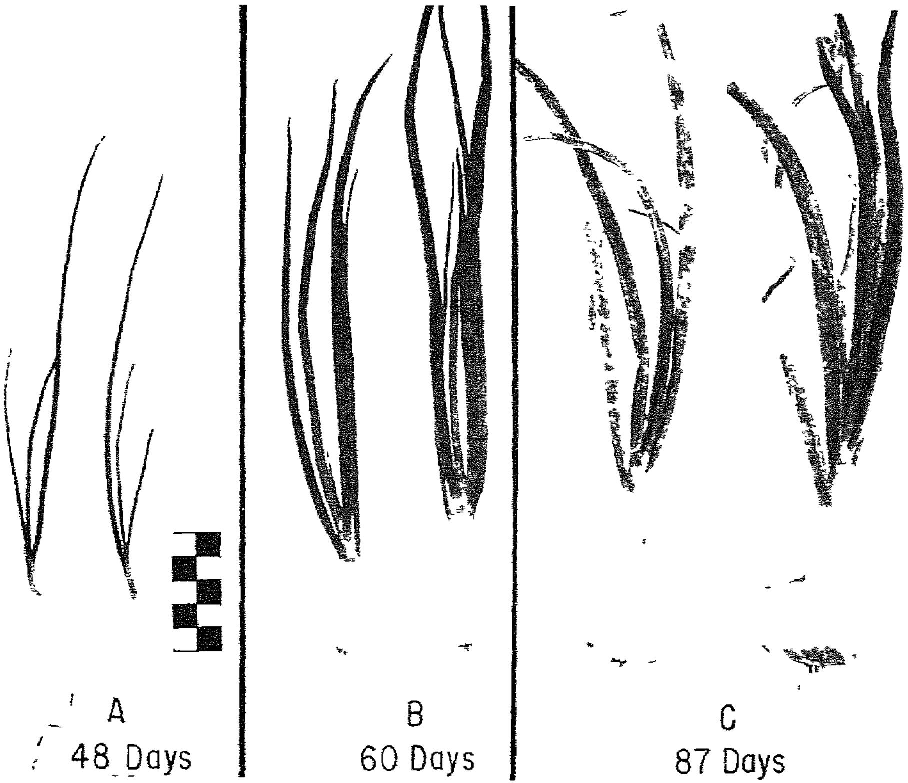
Allium tuberosum (CHINESE CHIVES)

Like *A. fistulosum* and *A. schoenoprasum*, Chinese chives differ from *A. cepa* in that they have no well-developed bulb; all the leaves are foliage leaves, and the lateral buds grow out immediately as tillers. As was mentioned in considering the inflorescence structure of *A. cepa* (p. 56), the inflorescence of Chinese chives is relatively simple, often consisting of only 2 cymes (Pl. 9(*b*)).

The stem of Chinese chives is more persistent than is that of any of the other food Alliums. In garlic, at one extreme, the whole stem of the mother plant dies at maturity; in Chinese chives, at the other extreme, the stem persists as a branched horizontal rhizome, resembling to a considerable extent the rhizome of the common bearded iris (cf. Pl. 14). The outer epidermis of the leaf-base is fibrous, and, as the leaves decay, these fibres coat the old rhizome as a tan-coloured or brown mat. It would appear that, in this species, the rhizome has largely replaced the bulb as a storage structure. Large, cord-like roots arise from the undersurface of the rhizome and, because of the persistence of the rhizome, probably function over a much longer period than do the roots of garlic. The plant may become dormant during the cold of winter, but there is no maturing with loss of roots as in *A. sativum*.

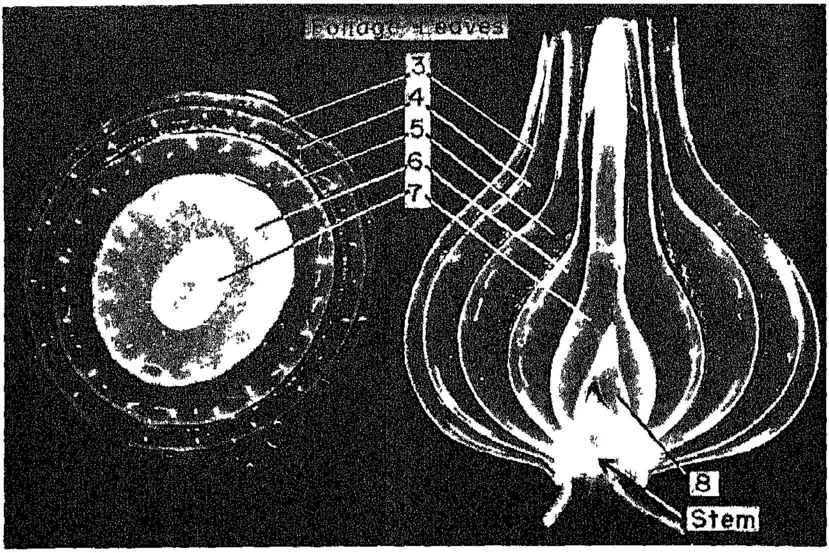
When one of the terminal inflorescences has been initiated, a lateral bud, in the axil of the leaf immediately beneath the inflorescence, continues the vegetative plant axis, which, after forming 2 to 4 leaves, again produces an inflorescence. Each rhizome tip usually produces 2 to 4 inflorescences during the flowering season. Considerable detail on the pattern of seasonal growth is presented by Yakuwa (1961).

The foliage leaves (Fig. 3) are flattish, slightly keeled, and solid in cross-section. The scape is usually semicircular in cross-section, with sharp edges, and solid.

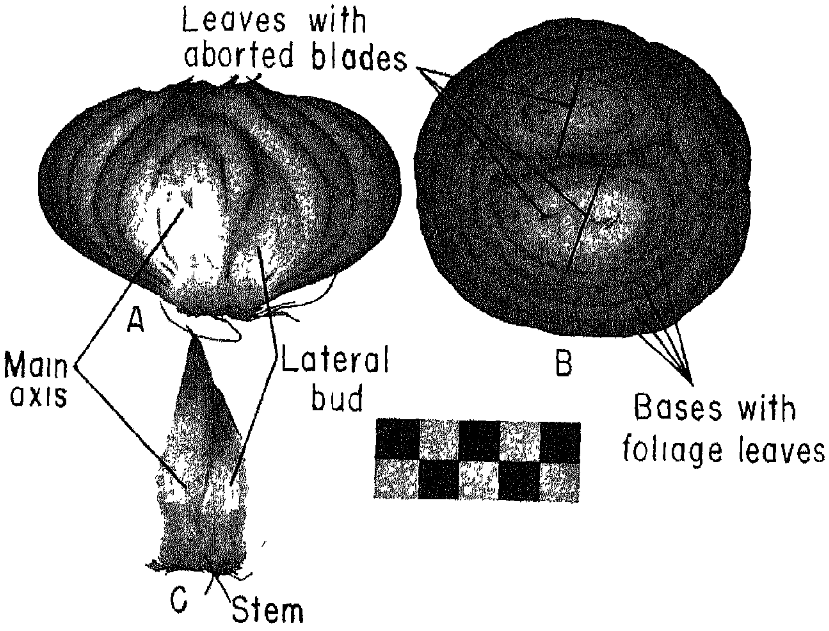


Allium cepa, 'Excel' Field-grown plants 48, 60, and 87 days from seeding In A, the dry cotyledon and three foliage leaves are visible, each plant possesses about 15 roots, and at the stem apex the 7th leaf is forming, bulbing has not started. In B, the second foliage leaf is still green, and bulbing has begun with the swelling of the bases of leaves 3–5; dissection at this stage shows that a lateral bud is present, usually in the axil of the 8th leaf, and that the 10th or 11th leaf has just formed, each plant now has about 28 roots In C, 2–3 foliage leaves have been lost and the following 6 leaves have swollen bases, the innermost being a leaf with an aborted blade; one or two lateral buds may make up a considerable portion of the bulb The 14th or 15th leaf is being formed near the bulb centre, and the number of living roots is now decreasing. The plants will mature in about 2 weeks Scale divisions = 1 cm.

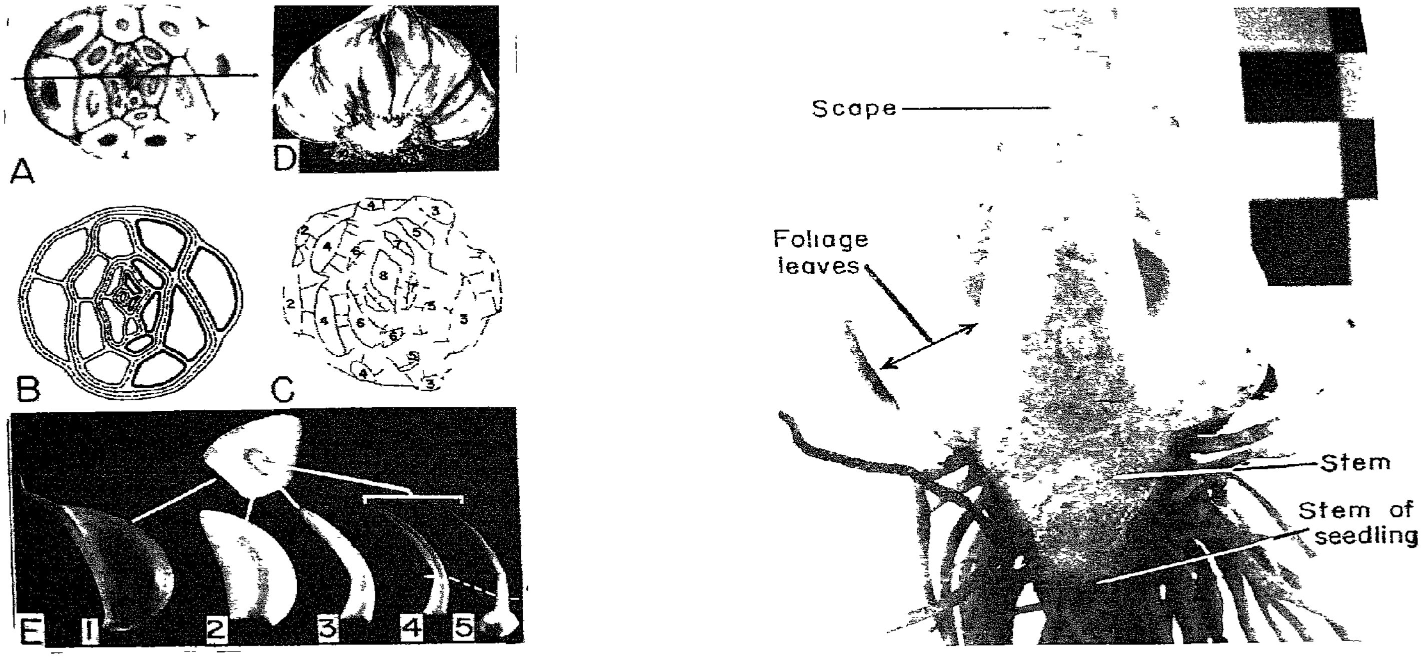
PLATE 10



(*a*) *Allium cepa*, 'Excel' Transverse and longitudinal sections of a bulb 74 days after seeding and about 2 weeks after the start of bulbing (cf Pl 10) Foliage leaf 2 is dry and has disappeared, foliage leaves 3–7 have thickened bases The blade of leaf 8 will probably abort, but the sheath of this leaf and those of the next 2 leaves will elongate to the top of the bulb and become thickened (cf Pl 11, B) A small lateral bud, present in leaf 8, is not visible in the photograph



(*b*) *Allium cepa*, 'Calred' A mature bulb in longitudinal section (A), in transverse section (B), and the central buds dissected from a bulb (C). All the outer scales in A and B arose from the main axis. The bladeless storage leaves are well shown in C. The bulb at B had 6 lateral buds, only 2 of which were of sufficient length to show in the cross-section Further dissection showed that the bulb centre at C had 3 lateral buds in addition to the one shown Scale divisions = 1 cm.

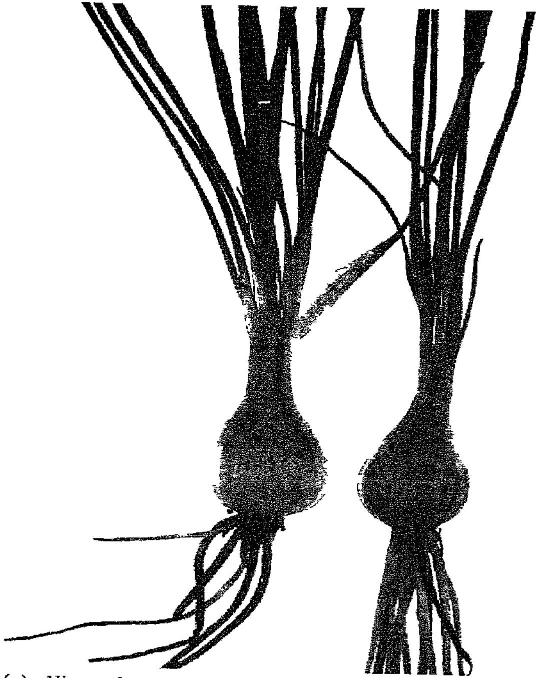


(*a*)

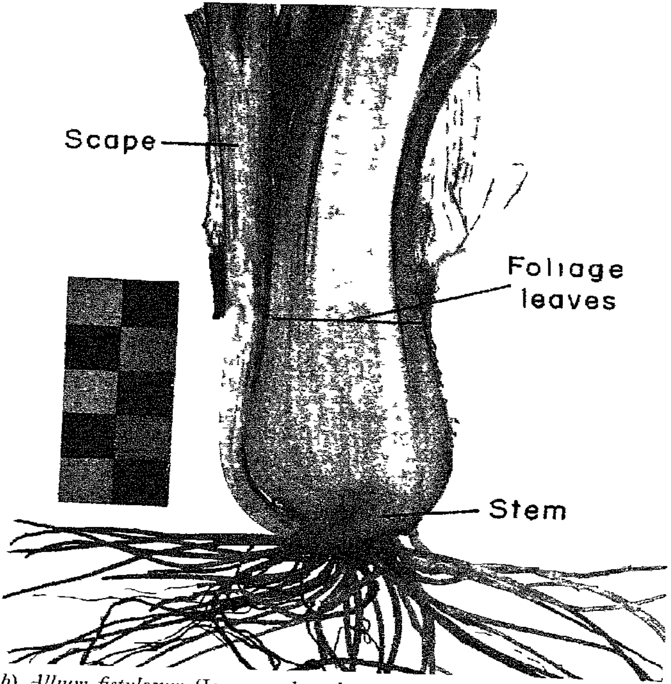
(*b*) *Photo Calif. Agric Exp Sta*

(*a*) *Allium sativum* (garlic). (A) Transverse section of a bulb, showing the arrangement of cloves The arrows indicate the direction of the two ranks of leaf-blades above the bulb (B) Drawing of A, showing the foliage leaf-bases surrounding the cloves The cloves on the right, in heavy outline were axial to leaves with blades ranked to the right (solid lines), the stippled cloves on the left were axial to leaves with blades ranked to the left (broken lines) (C) The stem of the bulb at A after removal of the cloves The numbered projections are the stem bases from which the cloves abscissed All cloves axial to the same leaf are numbered alike. (D) A mature bulb cut longitudinally to show the cloves and stem (E) Cross-section of a single clove, with the parts below in long-section as follows 1, protective leaf, 2, storage leaf, 3, sprout leaf (bladeless), 4, first foliage leaf, 5, second foliega leaf surrounding still smaller foliage leaves, all attached to the stem The broken line indicates the lower limit of the leaf-blades (Mann 1952)

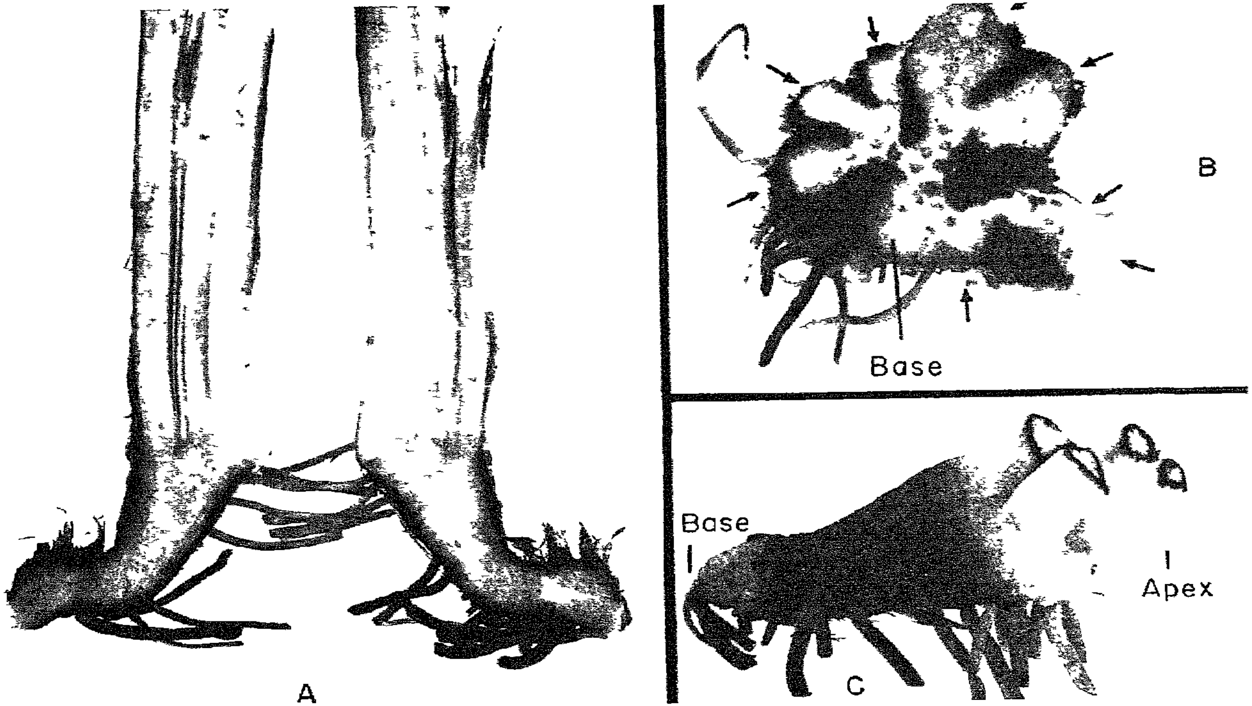
(*b*) *Allium ampeloprasum* (kurrat) Longitudinal section of the base of an 18-months-old plant, with solid scape and sheathing leaf-bases Many old leaves have decayed, but the vertical stem is intact and shows well how the stem broadens as it grows upwards No lateral buds have formed Scale divisions = 1 cm



(*a*) *Allium chinense* (rakkyo). Plants dug from the field in late August. These bulbs had not yet flowered, and each contained a single, short, unemerged inflorescence terminating the main axis. Most of the visible green leaves do not belong to the main axis but to developing lateral buds. In the bulb on the right there were 7 laterals in addition to the main axis; the bulb on the left had 10 lateral buds. By growth through the winter and spring, these laterals will develop to form a cluster of bulbs, replacing the old bulb. For scale cf. Pl. 9(*a*).



(*b*) *Allium fistulosum* (Japanese bunching onion). Longitudinal section of a plant harvested in late August showing the old scape (on left) and, occupying most of the section, the bulb made up of the relatively thin sheathing bases of the foliage leaves. The scape which was terminal on the main stem has been pushed aside by the lateral bud which continued the growth of the plant. The partly horizontal stem tends to persist as a poorly developed rhizome. Scale divisions = 1 cm.



Allium tuberosum (Chinese chives). (A) The basal part of a shoot that has been split lengthwise, showing the well-developed rhizome bearing roots on its lower surface and remains of fibrous leaf-bases on its upper surface. (B) The underside of a branched rhizome with the roots and stem partly cut away. The base is indicated, and the arrows point to the 8 separate tops which arose from this rhizome (one branch is not visible). (C) The tip of a rhizome from which the leaves have been removed, exposing the basal parts of 4 inflorescence stems. These have been outlined in black for easier visibility. For scale cf. Pl. 9(*b*).

PLATE 14

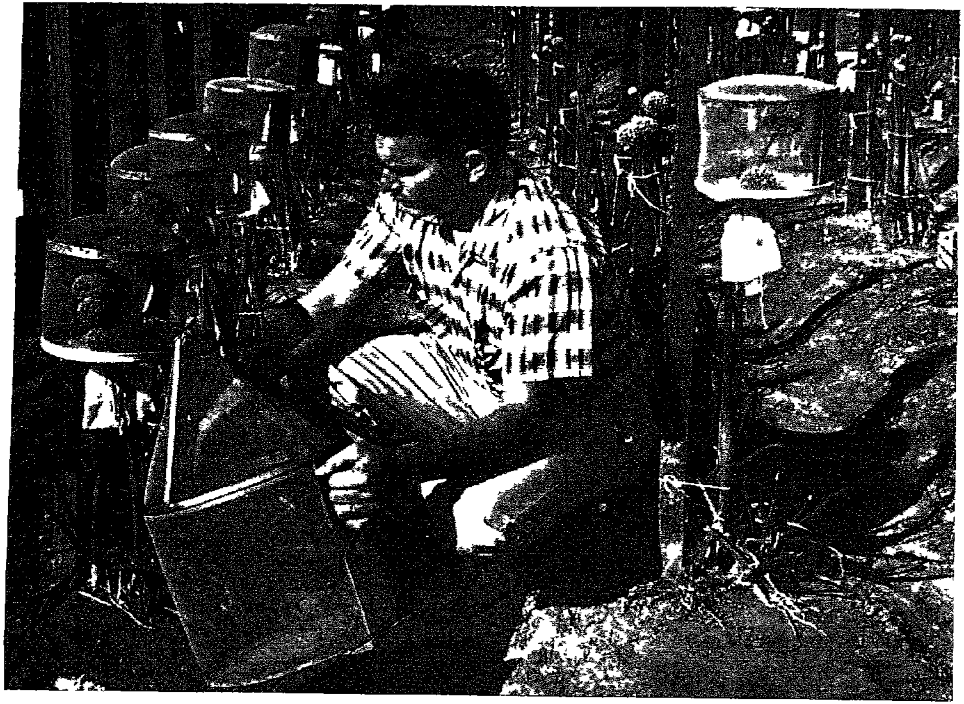


Photo Dessert Seed Co , Inc

(*a*) Self-pollination of onions Flower-heads are enclosed in metal-screen cages which have at the base a cloth sleeve that can be tied around the seed-stalks To avoid contamination by foreign pollen, the flowers must not touch the screen Flies, used as pollinators, are being transferred through the uncorked spout of the transfer cage and through a metal door into the selfing cage

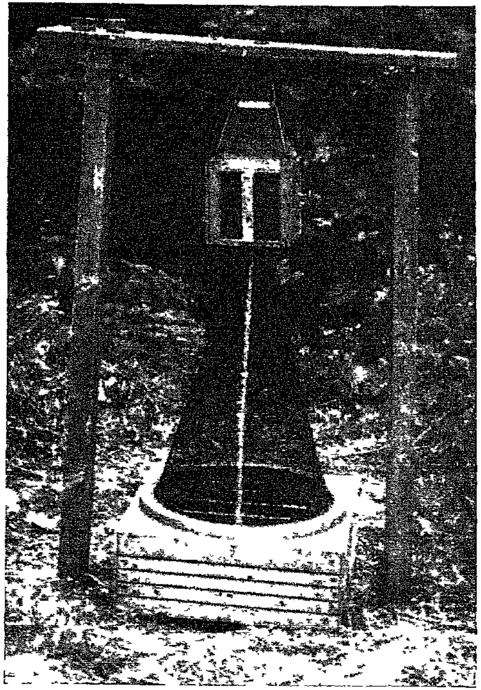


Photo U S Dep Agric

(*b*) Fly trap and transfer cage above it Meat, such as fish heads or beef lungs placed in the base of the trap, attracts wild flies The wooden strips are so placed that animals larger than flies cannot take the bait The flies enter the transfer cage through an opening in the bottom (cf Pl 15(*a*))

PLATE 15

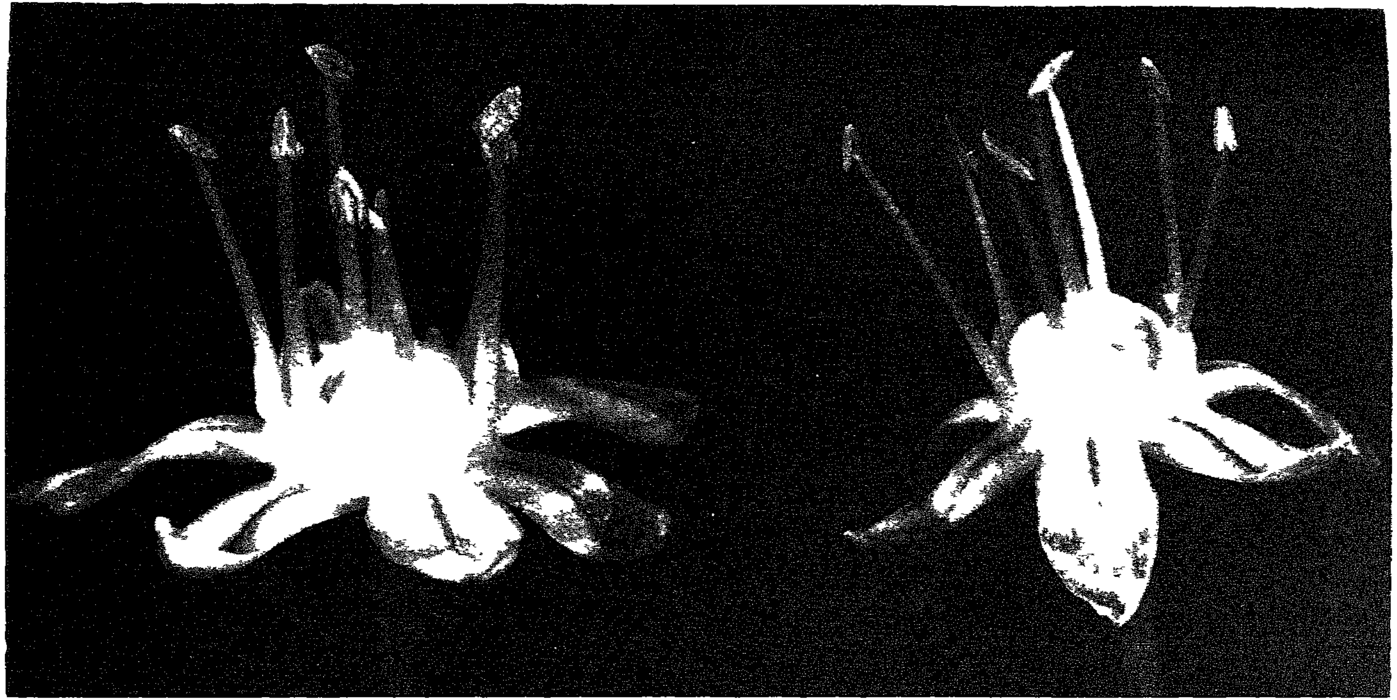
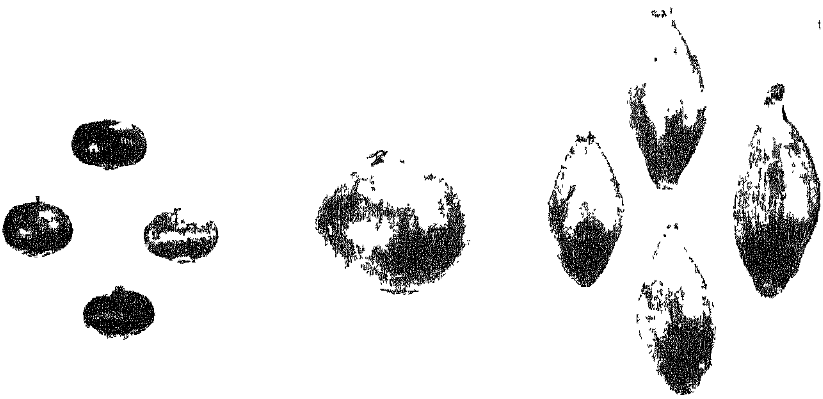


Photo U S Dep Agric

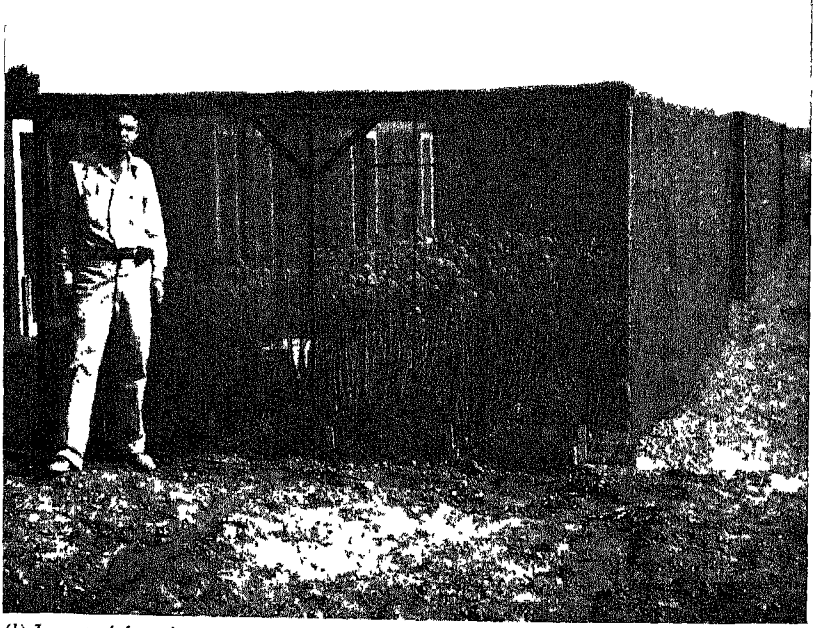
Normal and male-sterile flowers of the common onion The left-hand flower is male-fertile and, as indicated by its plump anthers, bears an abundance of pollen The flower of 'Italian Red 13–53' on the right is male-sterile While it produces no functional pollen in its anthers, it sets seed readily if pollinated from other plants Its use as a seed-parent in crosses avoids laborious hand-emasculation

PLATE 16



(*a*) A hybrid and its parents *Centre*, 'California Hybrid Red No 1', the first hybrid onion to be grown commercially, *left*, the pollen parent, Lord Howe Island', *right*, 'Italian Red 13–53', the male-sterile seed parent The vigour of the hybrid is evident

Photos U S Dep Agric



(*b*) Lumite (plastic) screen cages used to increase the A and B lines required for hybrid seed production Note hive of bees in the cage The screen is supported by a metal frame, is covered with soil at the base to exclude insects, and has a zipper in one corner for entrance.

PLATE 17

V

FOOD VALUE AND CHEMICAL COMPOSITION

'INDEED, of the many gifts that Europe owes to Asia, none, I imagine, have done more to reconcile man to a life of penury, than the vine and onion family. The labourer in Greek fields, with the traditional crust of bread, a skin of wine and a clove of garlic, could support his hard labour on those sunswept slopes. Even today his brother in England finds a lunch of bread and cheese a little tasteless without an onion.'

Thus Stearn (1946) quotes Bunyard to emphasize the value of the pungent garlic to enliven the food of the poor. Garlic, however, is no longer a flavouring for the poor alone, and the milder common onion and bunching onion are eaten in such quantities as to be reckoned as food in addition to flavouring. For the common onion especially, attention is being given to crispness, juiciness, mildness, and sweetness—characters which add delight to its eating. The onion breeder selects for many things. Good storage life is commonly associated with high pungency, and in selecting for better storage quality pungency may be increased. For example, as the Sweet Spanish-type onions have been selected for longer keeping, their pungency has gradually increased until they are no longer sweet onions. There is no reason to believe, however, that choice eating quality cannot be combined with qualities which make the onion easy to grow, harvest, and handle. The onion breeder is becoming more conscious of high food-quality, and, with the rapid advances in our knowledge of the chemistry of onions, he should be able to develop cultivars that are more suitable for both flavouring and eating.

FOOD VALUE

The value of any plant as a food crop depends on many factors: is it eaten as a staple or used only as a source of flavour? Is it high in food energy and a good source of protein, minerals, or vitamins? Can it be widely grown and economically produced? And is it available throughout the year in fresh or processed forms? Such subjective factors as taste and eye-appeal must also be evaluated. It is not surprising, therefore, that no simple method of arriving at food value has been devised. None the less, some useful comparisons can be made, such as those of MacGillivray and co-workers (1943, 1943*a*, 1943*b*) who, working during the period of food shortage in World War II, wished to establish

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the relative food value of several California vegetables that were being raised under conditions of land and labour shortages.

These workers assembled data on the energy, protein, calcium, iron, vitamin A, C, B_1, B_2, and niacin contents of vegetables, and expressed these values as ratios of the daily requirement of a moderately active man weighing 70 kg. (155 lb.). After this was done for 31 of the major California vegetables, the vegetables were ranked according to the content of these nutrients, on (1) a per-pound basis of the fresh product, (2) a per-acre basis, using average yields, and (3) a per-man-hour basis, using estimated labour requirements for the production of each vegetable. A rank of 1 indicates the highest food value, a rank of 31, the lowest. On the basis of nutrient content per pound of fresh vegetable, onions ranked about midway among the 31 vegetables considered. On the nutrients-per-acre basis, late onions ranked 3 (exceeded only by mustard greens and white potato) and early onions, 9. On the basis of nutrients per man-hour of labour for production, late onions ranked 6 and early onions 9 or 10.

The 31 vegetables were further grouped, on the basis of their nutrient content per pound, per acre, and per man-hour, into 4 groups. Onions fell into group 2, indicating that they are among our more efficient vegetables. Among processed vegetables, dehydrated onions assumed a similar rank.

Apart from these over-all comparisons, we should note that onions, compared with other fresh vegetables, are relatively high in food energy, intermediate in protein content, and rich in calcium and riboflavin.

As was stated in Chapter I, onions are now eaten, either as a substantial part of the diet or as a flavouring, by nearly every nation of the world. In the United States, the *per capita* consumption of onions averaged 16·6 lb. (7·5 kg.) per year for the period 1937–41—a figure only slightly below that of tomatoes, and sixth among the common vegetables. Other countries with very high consumption rates of onions are (*per capita* for the year 1954): Greece, 17·3 kg.; Spain, 14·4 kg.; Israel, 12·8 kg.; Turkey, 12·3 kg.; and Egypt, 9·3 kg. These are probably conservative estimates, as they are derived from population figures and production data (adjusted for imports and exports), which would not include home-grown crops.

VALUE AS ANIMAL FOOD

Onions are eaten by other animals than man, and where wild onion species are abundant, as they are in many areas of the Northern Hemisphere, they are highly palatable to cattle and sheep, although apparently not to horses. In the western United States, some species may be so abundant as to form an important item of range food for cattle, sheep, native deer, and bear (Dayton *et al.*, 1937).

Onion wastes from harvested fields or from other sources may be a valuable food for domestic animals. Although sheep are reported not to eat garlic, they eat onions with relish, and even consume bulbs that are still in the soil in unharvested fields. Miller (1945) reports a study comparing dried onion waste (peelings and bruised onions from a commercial onion dehydrator) with whole barley for fattening lambs. The onion waste (10·9% moisture, 8·6% protein, 5·8% ash, 4·8% fat, 18·3% crude fibre, and 51·6% N-free extract) was similar in composition to dried beet pulp—except for the higher fibre content of the onion waste. In a 45-day feeding trial, lambs fed on whole barley and alfalfa hay were compared with those fed on onion waste and alfalfa hay. Two types of onion waste were used, one having been dehydrated directly, and the other having had some water removed by pressing before dehydration. Miller observed that the onion waste was palatable, did not cause scouring, and had considerable nutritive value for the lambs. Barley-fed lambs gained about 0·30 lb. per day; those fed on pressed onion waste, 0·36 lb. per day; and those fed on unpressed waste, 0·40 lb. per day. Considering costs that were current at the time, the onion-fed lambs made the best economic gain. After slaughtering, the carcasses of the barley-fed lambs graded 19 choice, 4 good, and 1 commercial, while the two lots of onion-fed lambs both graded 22 choice and 3 good. Flavour and palatability tests indicated some off-flavour when onions were fed within 12 hours of slaughter, but none when onion feeding was discontinued 60 hours before slaughter. The official meat-grader commented favourably on the covering and finish of the onion-fed lambs, and there were no complaints from the retailers or consumers.

Whenever onions are consumed by cattle or other domestic animals, care must be taken to prevent onion flavour from carrying over into the food products obtained from the animals. In many countries the weedy wild garlic (*Allium vineale* L.) taints the milk of pastured dairy herds and gives off-flavours to beef and poultry. Talbot (1929) states that cows should be removed from pastures infested with wild garlic 4 to 7 hours before milking, to eliminate the garlic flavour and odour from their milk. Wylie & Harrison (1939) state, however, that cows on heavily-infested pasture may give flavoured milk up to 72 hours after removal from the pasture, and offer suggestions for the handling and use of tainted milk.

The offensive breath of humans who have eaten onions or garlic may last from a few hours to several days. Haggard & Greenberg (1935) review several theories on the source of this odour, and conclude from some quite convincing tests of their own that the odour comes from particles retained in the mouth, and not from the lungs (via the bloodstream) as some workers have supposed. Brushing the mouth with soap and water or with 30 per cent alcohol was of no help, but certain chemical preparations did remove the odour. Certainly in cows, where the milk may be flavoured within a very few minutes after onions are eaten (Wylie & Harrison, 1939), the odour and flavour constituents must enter the bloodstream quickly. Perhaps they do likewise in humans, but do not pass into the air of the lungs. The common belief that onion odours may appear in the sweat of persons who have eaten onions or garlic appears not to have been investigated.

Wild garlic also contaminates cereal foods, because its inflorescence bulbils are similar in size and shape to wheat grains, and are difficult to remove in thrashing (Richens, 1947; Iltis, 1949).

Major Chemical Constituents

Gross analyses of onion bulbs for carbohydrates, fats, proteins, minerals, and vitamins are given by Watt & Merrill (1950), and Orr & Watt (1957) give amino-acid contents of onion bulbs for 11 of the common amino-acids. Carbohydrates made up the bulk of the dry-matter of the onion bulb and, on a fresh-weight basis, protein constituted 1·4 per cent and fat 0·2 per cent. In 100 gm. of raw bulb tissue there were 50 International Units of vitamin A, 0·03 gm. of thiamine, 0·04 mg. of riboflavin, 0·02 mg. of niacin, and 9·0 mg. of ascorbic acid.

Sugar content of onion bulbs has been measured in numerous physiological studies. Bennett (1941), reporting 2 years' work, measured reducing sugars (as glucose) and non-reducing sugars (as sucrose) of 'Ebenezer' onions when they were placed in storage and after 3½ months of storage. In the first year the bulbs contained, on a dry-weight basis at the beginning of storage, 60 per cent of non-reducing sugars and 5·2 per cent of reducing sugars; in the second year, the contents were 42 per cent and 17 per cent, respectively. The percentage loss of total sugars varied from 3·0 to 8·1 per cent, depending on storage conditions. However, reducing sugars increased in all storages, especially at low temperatures (33° to 34°F.), where during the first year they rose from 5·2 to 21 per cent and, during the second year, from 17 to 29 per cent. Karmarkar & Joshi (1941) also found that reducing sugars increased during low-temperature storage, and this was again observed by Yamaguchi *et al.* (1957), working on 'Southport White Globe'. These latter workers also found, contrary to Bennett's observation, that reducing sugars exceeded non-reducing sugars at the start of storage.

Reporting carbohydrates as reducing or non-reducing sugars gives little indication of the sugars actually present. Joslyn & Peterson (1958) identified sucrose, glucose, and fructose, but did not specify the amounts present. Bacon (1957) found these same sugars and, in addition, a series of water-soluble, mainly non-reducing oligosaccharides whose chain-length did not exceed eight residues. No fructose polysaccharides were found. The oligosaccharides were absent from the outer scales, but constituted more than half of the soluble carbohydrates of the inner scales, where they were most abundant at the scale base.

Many of the quantitative data given above do not indicate the variability which might be expected among cultivars or in bulbs from different cultural and storage conditions. Mann & Hoyle (1945) reported that bulbs of 'Italian Red' may run as low as 6 per cent of dry-matter, while 'Southport White Globe' bulbs may exceed 18 per cent. One might also suspect that food and mineral constituents may be variable, and that any attempt to arrive at specific figures for the constituents of 'onions'—i.e. without specifying cultivar, growing conditions, etc.—is bound to be misleading.

The carbohydrates of garlic contrast with those of the common onion, in that in garlic the bulk of the carbohydrates consists of fructosans of varying chain-length, rather than of simple sugars (Archbold, 1940; Belval, 1943; Belval *et al.*, 1948). As was pointed out by Archbold, fructosans are a difficult group of compounds to analyse precisely, and much remains to be learned about their occurrence in different onions. Starch is generally absent from all *Allium* species.

SULPHUR COMPOUNDS

(A distinctive characteristic of most members of the genus *Allium* is their onion or alliaceous odour. This accounts, in large part, for their use as a food and as a spice in cooking, and certainly was the basis for their centuries-old repute in medicine. In recent times it has been shown (Cavallito & Bailey, 1944; Ark & Thompson, 1959; Virtanen & Matikkala, 1959) that garlic and onion extracts have potent antibacterial properties, and it is now known that organic sulphur compounds are responsible for these properties and for the alliaceous odour.)

Oil of garlic, prepared by steam distillation of ground garlic tissue, has an extremely unpleasant and penetrating odour, and consists principally of diallyl disulphide and lesser amounts of several other organic sulphides. The pleasant and characteristic odour given off when fresh garlic is sliced or crushed is quite distinct from that of garlic oil. Neither the compounds which give rise to the odour of garlic oil, nor those which give the aroma to crushed garlic, appear to be present in uninjured garlic cloves. If garlic cloves are quickly frozen, dried while still frozen, and ground, the dry powder has little or no odour.

A large number of workers have studied the sulphur compounds of onions and garlic. Some have worked largely with the vapours or distillates of ground pulp (Semmler, 1892, 1892*a*; Challenger & Greenwood, 1949; Niegisch & Stahl, 1956; and Carson & Wong, 1957, 1961), while others have studied the transformations which take place when tissues are injured (Cavallito *et al.*, 1944, 1945; Stoll & Seebeck, 1951; Matsukawa *et al.*, 1953; Renis & Henze, 1958; Fujiwara *et al.*, 1958;

and Virtanen & Matikkala, 1959). The results of these studies may be briefly summarized as follows:

A colourless, odourless, water-soluble amino-acid known as *alliin* is present in uninjured garlic. On injury of the cells, an enzyme, *alliinase,* comes in contact with alliin, and causes its breakdown into a sulphur-containing product, *allicin.* Allicin is the anti-bacterial substance of garlic, and has the typical odour of fresh garlic. It is unstable and breaks down into the strong-smelling constituents of garlic oil. The structures of both alliin and allicin are well established.

The alliin of *Allium sativum* contains an allyl radicle from which is derived the pungent diallyl disulphide of garlic oil, and possibly also the other allyl products observed. Smaller amounts of the methyl, and possibly the propyl homologues of alliin, are also present. *Allium cepa,* on the other hand, apparently contains methyl and propyl derivatives of alliin, but no true alliin. These differences account, at least in part, for the distinctive odours and flavours of these two species, and for the differences among the distilled products as described above—garlic oil yielding largely allyl compounds, and onion oil yielding methyl and propyl compounds.

Fujiwara and others have shown that several onion species differ considerably in their content of these alliin homologues, and that *Ipheion uniflorum* Raf., another member of the Amaryllidaceae, contains the ethyl derivative of alliin, a homologue that has not been found so far in any *Allium* species. The methyl homologue of alliin has been found in four families of dicotyledonous plants, but the enzyme alliinase has never been found with it. This methyl homologue constitutes a large proportion of the sulphur-bearing free amino-acids in the common cruciferous crops, and its breakdown yields dimethyl disulphide, the main aromatic of cooked cabbage (Morris & Thompson, 1955; Dateo *et al.*, 1957). Although alliinase has not yet been reported from other genera than *Allium*, an enzyme (called C-S-lyase), which splits alliin and similar compounds, has been isolated from the endosperm of seeds of the woody legume *Albizzia lophantha* Benth. (Schwimmer & Kjaer, 1960).

Fujiwara & Watanabe (1952), Matsukawa *et al.* (1953), and others, have shown that allicin (or its homologues) of onions reacts with thiamine (Vitamin B_1) to form compounds which they call allithiamines. Allithiamines, although not responding to some of the common tests for thiamine, are absorbed from the human intestinal tract more readily than is thiamine, and, because they can be utilized by the body, may increase the intake of thiamine from foods. These authors suggest, for example, that raw onions should be eaten with cruciferous crops to make the vitamin B_1 of the latter more readily available.

Much yet remains to be learned about volatiles in onions. There is no complete agreement on the nature of the 'tear-producing' essence (Challenger & Greenwood, 1949; Kohman, 1952; Wilkens, 1961;

Virtanen, 1962). While distinct from allicin and its homologues, it appears to be enzymatically produced, but its instability has made difficult its chemical identification.

No clear picture has yet emerged of the role of these many volatile constituents in contributing to odour, taste, and pungency. Onion 'pungency' or 'strength' is difficult to define and to measure, although, to help breeders and processers, many objective methods of measuring pungency have been proposed (Platenius, 1935; Currier, 1945; Jäger, 1955; Farber, 1957; Schwimmer & Weston, 1961). These have usually been based on quantitative estimations of sulphur or, more recently, of the pyruvic acid liberated by the alliinase reaction. To be useful, such methods must be simple and rapid, and must agree well with sensory evaluations of pungency. The excellent paper of Schwimmer & Weston (1961) reviews much of the literature in this field.

Perhaps the most interesting point for the general reader is that the compounds which are responsible for alliaceous odours (and flavours, at least in part) are formed only after the onion has been cut or injured. Treatments such as heating or freeze-drying, which destroy or suppress enzymatic changes, reduce the formation of onion odours. Cooking offers a good example. The enzymatic destruction caused by cooking certainly accounts in large part for the differences in flavour, odour, and pungency, between cooked and raw onions. Likewise, onions and garlic are not blanched to destroy enzymes before dehydration, as this would reduce the pungency of the final product.

Onion and garlic oils, produced by steam distillation, are used to a limited extent for flavouring manufactured foods. France is the most important producer of both oils, and garlic oil comes also from Egypt, Japan, and Chile. World production is increasing, and it is estimated that current annual production of garlic oil is perhaps more than 500 kg., and of onion oil less than 100 kg. Information on the properties and composition of these oils is given by Guenther (1952).

Onions and garlic, like many strong-smelling or irritating plants, have had a traditional place in folk-medicine for many centuries (Grieve, 1931; Martiné, 1946; Stoll & Seebeck, 1951; Täckholm & Drar, 1954). Early uses ranged from a cure for smallpox, effected by applying chopped garlic in a linen cloth to the soles of the feet, to an almost plausible remedy for hysteria—'if sniffed into the nostrils, it will revive an hysterical sufferer' (Grieve). Although many, and perhaps all, onion species yield antibiotics and other physiologically active compounds, the use of *Allium* preparations in medicine today is quite limited. Some local use may be made of onion or garlic preparations in pulmonary conditions, for lowering blood pressure, as anthelmintics, as intestinal antispasmodics, and externally as rubefacients or irritants (Anon., 1947). A number of preparations containing dried garlic or garlic extractives are now marketed for medicinal use.

PIGMENTS

Pigments are not only conspicuous in onion flowers, where they range from bright yellow through purple to clear blue, but also in onion bulbs, which vary from the deep reds to pink, and through many shades of yellows and browns. Bulb colour may be subject to marked consumer preference—e.g. in the United States the demand for red cultivars is not generally as great as for yellow or white cultivars—and dehydrators avoid coloured bulbs in both onions and garlic, as consumers prefer a white product. In addition, dehydrators avoid yellow onion bulbs, as they are thought to be associated with occasional bitter flavours in the dried product.

Although considerable information is at hand on the inheritance of bulb colour (Chapter VI), little is known about the pigment combinations which produce these colours. Environmental factors, such as rain, light, temperature, soil pH, and soil fertility, are known to affect bulb colour. Thus Knott (1933) has shown that copper has a marked effect on the scale colour of yellow onions grown on muck soils in New York. The many influences of environment on bulb colour have been well summarized by Magruder *et al.* (1941*a*).

The red pigments of onion bulbs are anthocyanins (glucosides of cyanidin, cf. Joslyn & Peterson, 1958), and the yellow pigment is largely the flavonol quercetin (Perkin & Hummel, 1896; Kuroda & Umeda, 1951; Herrmann, 1958). Perkin & Hummel noted that the dry scales of yellow onions have long been used for dyeing Easter eggs, and quote a German work of 1825 on dyeing which pointed out that in German households onion skins were also used for dyeing woollen, linen, and cotton fabrics. The colours, which are 'fast and particularly brilliant', ranged from yellows through brown to grey, varying with the metallic salt that was used as a mordant. Perkin & Hummel first showed that the colouring matter was quercetin, a flavonol which is widely distributed in plants—either free or variously combined as glucosides.

Herrmann (1958), in a recent study of the flavonol and phenol compounds of onions, suggests that the brown colour of onion bulbs cannot be due entirely to the pale-yellow flavonol compounds, but that tannin-like materials, formed by the oxidation of protocatechuic acid, must contribute to the deep-brown colour.

On a dry-weight basis of the scales of a brown onion (cultivar not given), Herrmann found 4 per cent of quercetin and 1 per cent of spiraeosid, a glycoside of quercetin that had been reported previously from the flowers of two species of *Filipendula.* Two other unidentified quercetin glycosides were found in small amounts. Spiraeosid was also found in the white cv. Weise Frühlingszwiebel, and in the shallot—but not in the leek. Protocatechuic acid, first isolated from onions by K. P. Link *et al.* (1929), made up 0·45 per cent of the dry scales. Other phenolic substances in the scales, at concentrations of 0·01 per cent or less, were phloroglucin, catechol (*see also* K. P. Link & Walker, 1933), methyl ester of protocatechuic acid, and phloroglucinol carboxylic acid. Phloroglucin, catechol, and ferulic acid were isolated from fleshy scales, and the green leaves contained a little caffeic acid.

In addition to the flavonol and anthocyanin pigments of onion bulbs, undesired pink pigments sometimes develop during the processing of onion products (Joslyn & Peterson, 1958, 1960; Lukes, 1959). These pink pigments may be readily produced by storing, for several days, purees of fresh onion bulbs that have been acidified with acetic acid containing a trace of formaldehyde. The pink pigment, which is water-soluble and contains nitrogen, differs from other known red plant pigments. Its production involves both enzymatic and non-enzymatic reactions, and is markedly influenced by the presence of certain free amino-acids and aldehyde compounds in the onion juice. Many species of Alliums show the pinking reaction, and possibly the green or blue discolorations of garlic purees are similar (Joslyn & Sano, 1956; Shannon, 1961). These discolorations of onion products can present serious problems to the onion processer. Further work on their nature and formation is needed.

SUBSTANCES ASSOCIATED WITH DISEASE RESISTANCE

(It has been known for many years that the smudge disease of the common onion, and, to a lesser extent, neck-rot, attack white bulbs much more readily than coloured bulbs. Investigations (K. P. Link *et al.*, 1929; K. P. Link & Walker, 1933) aimed at determining the basis for this resistance showed that two water-soluble phenolic compounds, protocatechuic acid and catechol, which are present in the dry outer scales of coloured onions, are toxic to the fungi causing these diseases (Chapter XV). These compounds appear to account for much of the resistance of coloured varieties.) White bulbs lack these compounds and, although the inheritance of scale colour in the onion bulb is quite complex (Chapter VI), protocatechuic acid and catechol always appear to be associated with the scale pigment. This association may be partly explained by Herrmann's (1958) suggestion that the phenolic compounds oxidize to brown pigments as the scales dry. Thus bulbs containing phenolic compounds would never be classified as white. Living, fleshy scales of coloured bulbs are not resistant to neck-rot and smudge, and Walker (1950) suggests that the reason for this may be that the toxic materials do not readily diffuse from living cells to the tissue surface (as they do from dry scales) and, further, that these compounds are somehow destroyed as the fungus invades the living cells. The resistance of the coloured cultivars to smudge is considerable, and affords one means of control where this disease is serious (Chapter XV).

Campanile (1924) has pointed out that the germination of conidia of *Helminthosporium allii* Campanile, a fungus which attacks white garlic cultivars more readily than coloured ones, was checked by a strong water extract from the dry outer scales of red bulbs; and Ramsey *et al.* (1946) have shown that spores of the fungus causing *Diplodia* rot of white onions do not germinate, or do so abnormally, in the presence of coloured onion scales. Other fungi may act differently, however; the black mould fungus, *Aspergillus niger* Tiegh., attacks coloured onion bulbs as readily as, or more readily than, white ones.

It has also been observed that certain fungi, like many bacteria, are susceptible to the volatile or non-volatile antibiotics that are found in freshly-crushed onion or garlic tissue. The smudge organism, however, which is susceptible to the volatile fraction of onion *in vitro* (Walker, 1923), readily attacks fleshy onion scales. None the less, the fact that strongly pungent cultivars are more resistant to neck-rot and smudge than are weakly pungent ones, suggests that these volatiles or their precursors may be involved in disease resistance. Smalley (1957) has shown, for a number of species of *Penicillium* belonging to the Fasciculata section of the genus, that the *in vitro* growth of strains of *P. corymbiferum* Westling, actually isolated from diseased garlic (*see* 'Penicillium decay', ibid.), was less strongly inhibited by fresh garlic juice than was the growth of strains or species that did not attack garlic in the field. However, at least some of the antibiotic volatiles which are produced by crushed tissue do not occur in uninjured tissues, so that their role in disease resistance is less clear than that of protocatechuic acid and catechol. Further details and references may be found in Hatfield *et al.* (1948) and Walker (1950).

Recently, Ark & Thompson (1959) have shown that aqueous extracts of dried garlic, applied as sprays or dusts, effectively control downy mildew (*Pseudoperonospora cubensis* (Berk. & Curt.) Rostow.), cucumber scab (*Cladosporium cucumerinum* (Ell. & Arth.)), and angular leaf-spot (*Pseudomonas lachrymans* (E.F.Sm. & Bryan) Carsner), on young cucumber plants. Similarly, bean plants were protected against bean anthracnose (*Colletotrichum lindemuthianum* (Sacc. &. Magn.) Briosi & Cav.) and a bacterial blight (*Pseudomonas phaseolicola* (Burk.) Dows.), and peach fruit and potted almond and apricot plants were protected from brown rot (*Monilinia fructicola* (Wint.) Honey). Ark & Thompson suggest that such antimicrobial agents originating from food plants deserve more attention, because, when used on other food plants, they leave no hazardous residues.

VI

GENETICS AND CYTOLOGY

In comparison with such crops as maize, barley, and wheat, very few genetic studies have been made on the onion. However, its large and easily stainable chromosomes have always made it a favourite for cytological studies, both in the classroom and in the research laboratory. Chromosome counts on many species of *Allium* indicate that the common basic number (n) for the genus is 7 or 8, with a few species having 9 chromosomes. The species that are cultivated for food all have the basic number $n = 8$: *A. cepa*, *A. sativum*, and *A. fistulosum*, are known only as diploids ($2n = 16$); *A. schoenoprasum* is known as $2n$, $3n$, and $4n$; *A. ampeloprasum* as $4n$ and $6n$; *A. chinense* as $2n$ and $4n$; and *A. tuberosum* as $4n$. Numerous papers discuss, in detail, meiosis and mitosis in the different species of *Allium*. Interested readers are referred to the works of Levan (1935, 1936–37), Emsweller & Jones (1935, 1935*a*, 1938, 1945), Maeda (1937), and Cochran (1953). The extensive bibliographies of some of these papers provide further references.

Genetic studies on male-sterility in the onion have had a stimulating effect on onion breeding. It is now possible for seedsmen to control their basic breeding lines and capitalize on new and worth-while introductions. Inheritance studies on onion bulb colour have provided information that is useful in the development of new cultivars, and have shown growers how to arrange their seed fields to minimize colour contamination. The few studies that have been made on species hybrids and polyploids indicate that this is a tremendously fertile field for investigation. Vegetatively propagated species, such as *A. sativum*, need to be made fertile to facilitate cultivar improvement. No doubt many of the wild species have genes for hardiness, disease resistance, etc., that could be incorporated into cultivars by the use of genetic procedures which are now available. Inheritance of disease resistance is discussed in Chapter VII.

MALE-STERILITY

The history of practically all of the hybrid onion seed produced in the United States today can be traced back to a single male-sterile (female) onion plant which was found in the vegetable breeding plots of the University of California at Davis in 1925. Because of its impact on plant breeding in general and on onion breeding in particular, this plant is of special interest. In the early autumn of 1924, 63 'Italian Red' bulbs were selected from a commercial lot and planted in the field at Davis (H. A. Jones & Clarke, 1947). The plants were grown through the winter, and the following spring the flower-heads were enclosed in Manila paper bags for self-pollination. The bags were tapped several times each day to distribute the pollen. In August, 1925, the seed-heads were harvested. The weather had been satisfactory for seed setting, and most of the plants gave a good supply, one especially good plant producing nearly 6,000 seeds. On 15 plants, however, no seed was produced. Some of this sterility may have been due to seed-stem rot. One of the seedless plants, pedigree 13–53, differed from the other sterile ones in that the seed-heads were packed with small sets or bulbils among the florets; its 5 seed-stems had 136 sets. As later studies have shown, this plant failed to produce seed because it was male-sterile—i.e. because it produced no functional pollen. The ability of this plant to produce head sets saved it from extinction: since 1925, 13–53 has been propagated vegetatively by the use of these small bulbils. As they do not store well, these bulbils must be planted soon after harvest. At Davis they are planted in the field in early autumn and over-winter as growing plants. The large spindle-shaped bulbs, which mature in July, are then planted in the field in September, for the production of more bulbils.

The clonal line 13–53 has been grown under a wide range of climatic conditions, and seed has never been produced when the flower-heads were protected from pollen by bagging or by isolation, which indicates that this type of sterility is not greatly influenced by environment. Barham & Munger (1950), at Ithaca, New York, found viable-appearing pollen on 13–53 and other male-sterile plants growing at 70° to 80°F., and some of this pollen germinated when placed on a sugar-agar medium. However, when these 13–53 plants were selfed, no seed was produced. It was thought that failure to get seed was due to the small amount of viable pollen produced, coupled with the tendency of the pollen to clump and the failure of the anthers to dehisce. No difference in the amount of viable-appearing pollen was found between the original 13–53 and male-sterile lines that had been back-crossed to fertile plants six or seven times. Barham & Munger found no viable-appearing pollen on plants growing at temperatures below 70°F., and concluded that the temperature to which flower-buds are exposed, from the time of formation of the tetrads until the first post-meiotic division is completed, determines whether or not viable-appearing pollen will be produced. They found no difference in pollen development on male-sterile plants under long and normal photoperiods.

A cytological study of sterility in 13–53 was made by Monosmith (1928). Whereas she found the normal chromosome complement, and whereas meiosis proceeded regularly, the microspores degenerated so that no viable-appearing pollen was produced. The first indication of abnormality was the hypertrophy of a few of the centrally-located tapetal cells. These degenerated abnormally and, following this, many or all of the microspores in a locule died. At the time of dehiscence, the contents of the pollen sac were cemented together and remained within the anther.

In the meantime, studies were being conducted on the mode of inheritance of male-sterility in 13–53 (H. A. Jones & Clarke, 1943). Male-sterility in 13–53 is interpreted as a condition resulting from an interaction between a recessive nuclear gene (chromogene) and a cytoplasmic factor (cytogene). It is assumed that there are two types of cytoplasm: normal (*N*) and sterile (*S*). All plants with *N* cytoplasm produce functional pollen; all male-sterile plants have *S* cytoplasm. A recessive gene for male-sterility (*ms*) also influences pollen development when carried in plants with *S* cytoplasm, but has no effect when carried by plants with *N* cytoplasm. Consequently, the 13–53 male-sterile plants belong to the genotype *S ms ms*. Plants with *N* type cytoplasm are always male-fertile, and may be either *N Ms Ms*, *N Ms ms*, or *N ms ms*. When plants having these different genotypes are crossed with the male-sterile *S ms ms*, the following results are obtained:

Female (male-sterile)		Male (male-fertile)		F_1	Ratio
S ms ms	×	*N Ms Ms*	→	*S Ms ms*	All fertile
S ms ms	×	*N Ms ms*	→	*S Ms ms* + *S ms ms*	1 fertile: 1 sterile
S ms ms	×	*N ms ms*	→	*S ms ms*	All sterile

Plants with the genetic constitution *S Ms Ms* and *S Ms ms* will always be fertile, because they carry the dominant gene *Ms*. The sterility factor *S* is inherited only through the egg, and not through the male parent. The method of inheritance is illustrated in Fig. 6. Neither the genetic factor *ms*, nor the cytoplasmic factor *S*, alone is enough to cause male-sterility; plants must have both these factors to be male-sterile (Fig. 6).

With this picture of the genetics of male-sterility in mind, it is clear that, by the use of 13–53, male-sterility can be introduced into other cultivars. This may be done by either of two methods. The first, and simplest, can be used if plants of the *N ms ms* genotype can be found in the cultivar in question. Such plants are widespread and may be detected by the methods given in Chapter VII. Once *N ms ms* plants have been found, a male-sterile line can be developed for the cultivar by repeatedly back-crossing male-sterile plants to these. Fig. 7, from H. A. Jones & Davis (1944), illustrates how this was done with *N ms ms* plants found in 'Crystal Wax'. After four or five back-crosses, the *S ms ms* and *N ms ms* lines are almost identical, except that one line is sterile and the other fertile. These lines are called the A and B lines, respectively, and are propagated as indicated in Fig. 8.

A second method must be used for certain cultivars which do not carry the recessive genes *ms*—i.e. in which all plants are *N Ms Ms*. In these it is possible to incorporate the *ms* gene by the following procedure:

(1) *S ms ms* × *N Ms Ms* · · *S Ms ms*
(2) *N Ms Ms* × *S Ms ms* · *N Ms Ms* + *N Ms ms*
(3) *N Ms ms* selfed · · *N Ms Ms* + *N Ms ms* + *N ms ms*

(1) Male-sterile plants (*S ms ms*) are crossed with male-fertile plants (*N Ms Ms*), giving F_1 plants of the genotype *S Ms ms*, which are fertile.

(2) These fertile *S Ms ms* plants are crossed with *N Ms Ms*, the latter being emasculated and used as the seed parent. The two types of progeny obtained, *N Ms Ms* and *N Ms ms*, are fertile and identical in appearance, but can be distinguished by a progeny test. When *N Ms Ms* is crossed with *S ms ms*, all of the progeny will be fertile; when *N Ms ms* and *S ms ms* are crossed, half of the progeny will be male-fertile and half male-sterile.

(3) When the *N Ms ms* from (2) is selfed, it yields three kinds of progeny: *N Ms Ms*, *N Ms ms*, and *N ms ms*, all of which are male-fertile. Again, by a progeny test, the *N ms ms* plants can be identified, as only these yield all male-sterile plants when crossed with *S ms ms*.

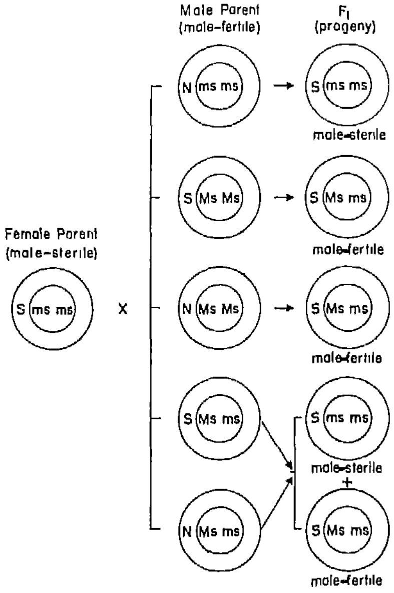

FIG. 6.—The inheritance of cytoplasmic-genetic male sterility in the onion. Letters in inner circles (nuclei) represent genetic factors; letters in outer circles represent cytoplasmic factors. *S* and *ms* are factors for sterility; *N* and *Ms*, factors for fertility.

The desired B line of the new cultivar has now been established, and this makes it possible to develop an A line, with the aid of the new B line, by the back-cross method shown in Fig. 7. The male-sterile line used for the initial cross to the B line should resemble it in all important characteristics.

A third method of developing male-sterile lines in new cultivars is to search in large plantings for naturally-occurring male-sterile plants (*S ms ms*). These have been found in a number of cultivars. If *N ms ms* individuals can also be found, the development of male-sterile lines is greatly facilitated, as no unwanted genes are introduced by crossing outside of the cultivar.

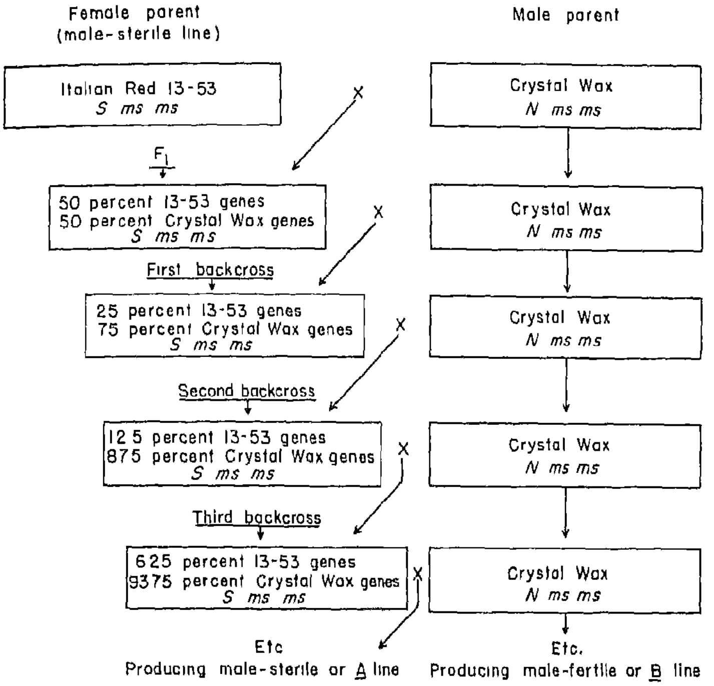

FIG. 7.—Method of developing a male-sterile line of 'Crystal Wax', using the male-sterile 'Italian Red 13-53'. The rate at which 'Crystal Wax' genes are incorporated into the male-sterile line by back-crossing is indicated (H. A. Jones & Davis, 1944).

By whatever method the A and B lines are developed, Fig. 8 illustrates graphically how they are perpetuated. In the next chapter we shall discuss how these lines are used for the production of hybrid seed.

Recently, Nishi & Hiraoka (1958) reported a monogenic, recessive type of sterility in *A. fistulosum*, where pollen abortion in the anthers is caused by the enlarging of the tapetal cells immediately after the tetrad formation of the microspore mother-cells. The enlarged tapetal cells, with excessive vacuole development, seemed to oppress the tetrads.

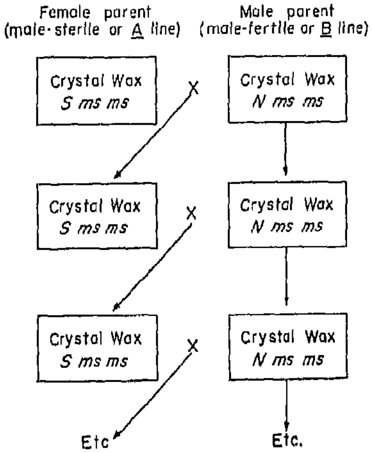

FIG. 8.—Method of perpetuating a male-sterile line of the cultivar Crystal Wax (H. A. Jones & Davis, 1944).

SPECIES CROSSES

Many investigators have made crosses between *Allium cepa* and *A. fistulosum*, with the object of getting a bulbing-type onion possessing the disease-resistant character of *A. fistulosum*. So far this objective has not been realized, but some information has accumulated regarding the F_1 hybrid. By the use of flies for pollination, Emsweller & Jones (1935) were able to get F_1 seed from crosses between *A. fistulosum* and *A. cepa* 'Crystal Wax'. In controlled crosses between 'Crystal Wax' and *fistulosum*, 135 seeds were obtained; in crosses between 'Yellow Bermuda' and *fistulosum*, 175 seeds were obtained. In 1932, at Davis, California, *fistulosum* and 'Australian Brown' were planted in adjacent plots in the field. In 1933, 32 species hybrids were found among the plants grown from the *fistulosum* seed on an area of about $\frac{1}{16}$ acre. They were recognized in the field by their vigour and semicircular leaves, and were typical of the hybrids produced under controlled conditions. In the second year, the floral characters and the sterility of these plants fully confirmed their hybrid nature. In 1933, *fistulosum* and 'California Early Red' were planted in adjacent plots and open-pollinated seed was collected. A population of 836 plants was grown from the *fistulosum* seed, of which 17 were hybrids. In a population of 5,000 plants grown from the 'California Early Red' seed, no hybrids appeared. Apparently these species cross to some extent in the open, but more readily in one direction than in the other.

Allium fistulosum is a non-bulbing species which continues growth throughout the summer and into the autumn as long as weather conditions are favourable. In contrast, *A. cepa* usually forms a resting bulb, which brings vegetative growth to a halt even though growing conditions remain favourable. The hybrid between these species, while forming a more conspicuous bulb than *A. fistulosum*, retains the growth-habit of the latter, remaining erect and continuing to grow throughout the summer. *A. cepa* usually starts to flower 6 to 7 weeks after *A. fistulosum*, and the hybrid is intermediate. In *A. cepa* the individual flowers open irregularly over the inflorescence surface throughout the flowering period; in *A. fistulosum* the terminal flowers open first, and flowering progresses towards the inflorescence base. In the hybrid the terminal flowers are the first to open, although with less consistency than in *A. fistulosum*, whereupon a wave of opening extends towards the base; but this does not terminate the flowering of the umbel, for flowering continues for a time over the entire inflorescence, as it does in *A. cepa*. In *A. fistulosum* the perianth segments remain erect; in *A. cepa* they become fully expanded. The flowers of the hybrid very closely resemble those of *A. fistulosum*. In most *A. fistulosum* cultivars the leaves are circular in cross-section, whereas in most cultivars of *A. cepa* the leaf-blade is semicircular; in the hybrid the semicircular type of leaf is dominant. Under similar growing conditions the hybrids exhibit much more vigour than either of the parents.

Practically all of the F_1 plants are self-sterile; from the hundreds of plants selfed, only a few F_2 seeds have been obtained. However, some functional pollen is produced, as it is possible to get back-cross seed when the F_1 is used as the pollen parent. Fertility, as measured by seed production, has been greater when back-crosses were made to the *fistulosum* parent. Clonal lines of the F_1 can be established and perpetuated by vegetative propagation.

Cochran (1953), at Baton Rouge, Louisiana, produced and studied the F_1 hybrid of *A. fistulosum* × shallot, using inbred lines for the *fistulosum* parent and commercial white shallot for the *cepa* parent. The results were similar to those described by Emsweller & Jones (1935) for their F_1 hybrid between *A. fistulosum* and cultivars of *A. cepa* belonging to the Common Onion group.

POLYPLOIDY

The production of amphidiploids is of considerable interest because of its importance in the origin of new fertile types. By a process of chromosome doubling, a sterile species-hybrid may sometimes be made fertile. In the *A. cepa* × *A. fistulosum* cross, the amphidiploid maintains all of the desirable attributes of the F_1, and in addition has some degree of fertility. H. A. Jones & Clarke (1942), at Beltsville, Maryland, found a natural amphidiploid among their hybrids from the cross *A. cepa* 'Australian Brown' × *A. fistulosum*. Besides being self-fertile, the amphidiploid had more vegetative vigour than either parent, as was evidenced by the more rapid growth of its seedlings, the increased size of the mature plant, the larger stomata and pollen grains, and the greater weight of individual seeds.

'Australian Brown' forms medium-size bulbs; *A. fistulosum* has only a slight tendency to enlarge in the lower sheath region. The amphidiploid does not form a mature bulb, but a much larger bulb develops in it than in *fistulosum*. The stomata of the amphidiploid are significantly larger than those of either parent or of the diploid hybrid. The length of the guard-cells of 'Australian Brown' measured 39·4 μ, of *fistulosum* 41·0 μ, of the F_1 diploid 41·8 μ, and of the amphidiploid 51·7 μ. The amphidiploid differs from both parents, and from the diploid hybrid, in that the first flowers of the umbel frequently open while still enclosed within the bract—instead of later, after the bract has been ruptured. The sequence of flowering and the growth-habit of the flower are similar to those in the F_1 diploid. The amphidiploid flower significantly outweighs the flower of 'Australian Brown', which, in turn, is larger than the *fistulosum* flower. The pollen of the amphidiploid is larger than that of either parent or of the diploid hybrid. The weights of 100 seeds of the amphidiploid, of *fistulosum*, and of 'Australian Brown', were 575, 190, and 492 mg., respectively.

At the first division of the pollen mother-cells of the amphidiploid, there were usually sixteen pairs of chromosomes, and pairing was quite regular when compared with that of the diploid hybrid. Generally, *fistulosum* chromosomes paired with *fistulosum* chromosomes and *cepa* with *cepa*, but occasionally pairing occurred between *fistulosum* and *cepa* chromosomes.

S. T. Jones & Kehr (1957), at Baton Rouge, Louisiana, studied colchicine-induced amphidiploids of shallots (*A. cepa*, Aggregatum group) × *fistulosum*. The performance of this amphidiploid was similar to that of the Common Onion group cultivars × *fistulosum* amphidiploid described by H. A. Jones & Clarke (1942). When selfed, the amphidiploid set as much seed as the *cepa* parent, and showed an equal amount of stainable pollen. The amphidiploid normally formed sixteen bivalents, the *cepa* and *fistulosum* chromosomes pairing among themselves, but there appeared also to be some pairing between the *cepa* and *fistulosum* chromosomes.

H. A. Jones & Clarke (1942), and E. W. Davis (1955), showed that seed production in the amphidiploids was lower than in the parental species. No doubt there are a number of causes for this partial sterility. To overcome this sterility, E. W. Davis (1955) suggests: (1) selecting for increased fertility within segregating amphidiploid lines; (2) selecting of parental material for absence of genes causing sterility; and (3) crossing of autotetraploids of the two species involved, in which the parents have been selected for lack of genes causing sterility. Whether or not complete fertility can be restored by these methods remains to be determined.

COLOUR INHERITANCE

The attractiveness of a cultivar depends to a large extent upon the bulb colour. Among commercial onions there are four colour classes: white, yellow, red, and brown. Inheritance of white, yellow, and red colours is well known, but studies of brown have never been reported. Clarke *et al.* (1944) showed that a dominant basic colour-factor *C* is necessary for either red or yellow. All plants with *cc* have white bulbs, regardless of the presence of other colour-factors. Dominant *R* in the presence of *C* gives a red bulb colour. The recessive allele *r*, with *C*, produces a yellow bulb. The bulb colour-inhibiting factor *I* is incompletely dominant over *i*. Cultivars having the constitution *II* have white bulbs, regardless of the presence or absence of the *C* and *R* factors. Bulbs of the genotype *Ii CC rr* are cream or buff in colour, but *II CC rr* bulbs are white. A cultivar that is homozygous for red has the genotype *ii CC RR*; yellow is *ii CC rr*; recessive white can be *ii cc RR*, *ii cc Rr*, or *ii cc rr*.

H. A. Jones & Peterson (1952) report complementary factors for light-red bulb colour in crosses between the yellow Brazilian cultivar Pera Baia and the yellow onion cultivars Ebenezer, Early Yellow Globe, and Yellow Globe Danvers. When Pera Baia was crossed with the other cultivars, all of the progenies were red.

Complementary factors for yellow and light-red bulb colours are present in many recessive white cultivars; coloured bulbs appear in the F_1 when recessive whites are crossed.

In certain cultivars, especially Australian Brown and Giza No. 6, chartreuse bulbs which breed true for this colour occasionally appear.

A number of abnormal chlorophyll types have been studied by H. A. Jones *et al.* (1944). Inbred lines, especially, segregate seedlings with chlorophyll deficiencies. A very common one is albino (*a*), a monogenic recessive which soon dies. Another chlorophyll deficiency that is perpetuated in heterozygous plants is a light-yellow lethal inherited as a monogenic recessive. A seedling carrying this gene resembles the albino seedlings closely, except that it is light-yellow instead of white. There is strong evidence that at least two different pairs of genes operate, either of which may produce the yellow lethal condition. The pair which is linked with glossy has been designated as y_1, and the other, which assorts independently, as y_2. A third type of lethal, designated as pale green (*pg*), is also a monogenic recessive.

Seedlings such as the yellow and albino types die in an early seedling stage, but another abnormal-type seedling called virescent (*v*), found in 'Australian Brown', survives. At low temperatures, virescent seedlings are light green during early stages, but they become darker green at higher temperatures, so that at maturity the plants are not distinctive. Virescent is also inherited as a monogenic recessive. While the virescent plants survive under favourable climatic conditions, they remain smaller than normal plants, and the mature bulbs weigh only about one-half as much as those of normal plants.

The difference in foliage colour among cultivars is mainly due to the amount of wax secreted on the exterior surface of the leaf. The glossy surface of the foliage in the cultivar White Persian, in certain strains of Australian Brown, and occasionally in other cultivars, is due to a lack of this waxy secretion. Crosses show that non-glossy (*Gl*) is incompletely dominant over glossy (*gl*). Glossiness is inherited as a monogenic recessive. Crosses between the 'White Persian' glossy and the 'Australian Brown' glossy give non-glossy in the F_1, indicating that different genes govern their inheritance. In the cross between virescent and glossy, the F_1 plants are also non-glossy.

INHERITANCE OF OTHER CHARACTERS

Critical studies on the inheritance of many characters have not been reported in the literature. Observations seem to indicate, however, that time of maturity, shape of bulb, pungency, dry-matter content, and bolting habit, are conditioned by multiple genes.

VII

BREEDING

THE common onion, *Allium cepa*, is one of the most variable species of plants. Great differences exist in the size, shape, colour, firmness, percentage of dry-matter, pungency, and sweetness of the bulb; also in the colour of the foliage, reaction to day-length, resistance to disease and insects, length of the rest-period, retention of scales, and other characters. This variability is fortunate for the onion breeder as well as for the onion industry: because of it, the number of cultivars that can be developed is almost endless, and these can be 'tailored' to grow satisfactorily in most lands where crops can be cultivated. Not only can types be developed to fit specific growing conditions, but they can be fashioned for a wide range of uses. To attain these objectives is no easy matter, but it can be both a fascinating and a rewarding experience. An ideal onion cultivar should be attractive, resistant to diseases and insects, high-yielding, free from doubles and premature bolters, and uniform in size, shape, colour, and time of maturity. In addition, it should be capable of producing a good crop of seed. If designed for late storage, it should have a long rest-period for both roots and sprouts, hard flesh, and retentive scales to withstand mechanical handling. For dehydration purposes the bulbs need to be of high dry-matter content, white colour, and pungent taste. For use in salads the flesh should be sweet, mild, and crisp. Obviously, all of these characters cannot exist in any single cultivar, so it is necessary to have many cultivars for different purposes and adapted to different regions.

Not so many years ago, we had hoped that the number of cultivars could be reduced by developing a few that, individually, would be widely adapted, covering a considerable area. Recent studies show, however, that the onion plant is very sensitive to length of day, temperature, and other climatic conditions, and for this reason the range of adaptation of any single cultivar is rather limited. The best results will probably be obtained if cultivars are developed for particular regions and specific purposes. In general, mother bulbs, i.e. bulbs chosen for increase or breeding purposes, should be selected in the area for which the cultivar is being developed.

There are several methods of producing new or improved onion cultivars which, while using similar basic techniques, differ in their objectives and general approach. Selection, selfing, and mass-pollination within cultivars, have long been used to develop strains or new cultivars with improved uniformity and desired characteristics. More recently, the discovery of male-sterility has made possible the commercial development of hybrid seed. This seed, produced by crossing carefully-selected inbred lines, can yield a crop of vigorous and remarkably uniform bulbs. Hybrids of a quite different nature—between *Allium* species—have yielded some bunching-type onions of commercial value. Finally, either through careful selection or by back-crossing to commercially desirable types, disease- and insect-resistance or other specific characters may be incorporated.

IMPROVEMENT BY SELFING AND MASSING

If mother bulbs are carefully selected, it is possible to maintain fairly uniform stocks of cultivars. As onions are highly cross-pollinated, most of the standard commercial cultivars have a very mixed heredity, so that it is possible to select rather widely within a cultivar for specific types. Seldom do two people have exactly the same idea of what characteristics a cultivar should have, and consequently many different strains of present-day cultivars exist. By following the selection method exclusively, certain recessive colours and off-types can never be completely eliminated. For this reason it is well to do some inbreeding, to uncover and eliminate the undesirable attributes carried in the germ-plasm.

Most of the improvement work, especially by commercial seedsmen, aims to eliminate off-type plants and to improve cultivar uniformity as regards certain characters. This can best be done by selecting mother bulbs of the desired type, selfing these to secure uniform and true-breeding lines, and then re-selecting and massing to restore vigour. A suggested programme follows (Fig. 9).

First Year: Select at least 100 onion bulbs that approach the ideal for a cultivar; the larger the number selected, the better will be the chance of obtaining desirable lines. Plant these selected mother bulbs in late autumn, in winter, or in early spring, depending upon the location. Each bulb will become the parent of a separate line.

Second Year: Self-pollinate as described in the section on selfing (p. 87).

Third Year: Grow progenies of all selfed lines separately. Destroy undesirable lines during the growing-season, or at harvest time, or upon removal from storage. Keep 15 to 20 of the best bulbs of each of 25 or more of the most outstanding lines, and plant for selfing and open-pollination under good isolation.

Fourth Year: Self-pollinate about half of the umbels on each plant and allow the others to open-pollinate. By following this procedure it is possible to obtain a supply of open-pollinated seed of superior quality that can be massed and increased rapidly to quantity production. For

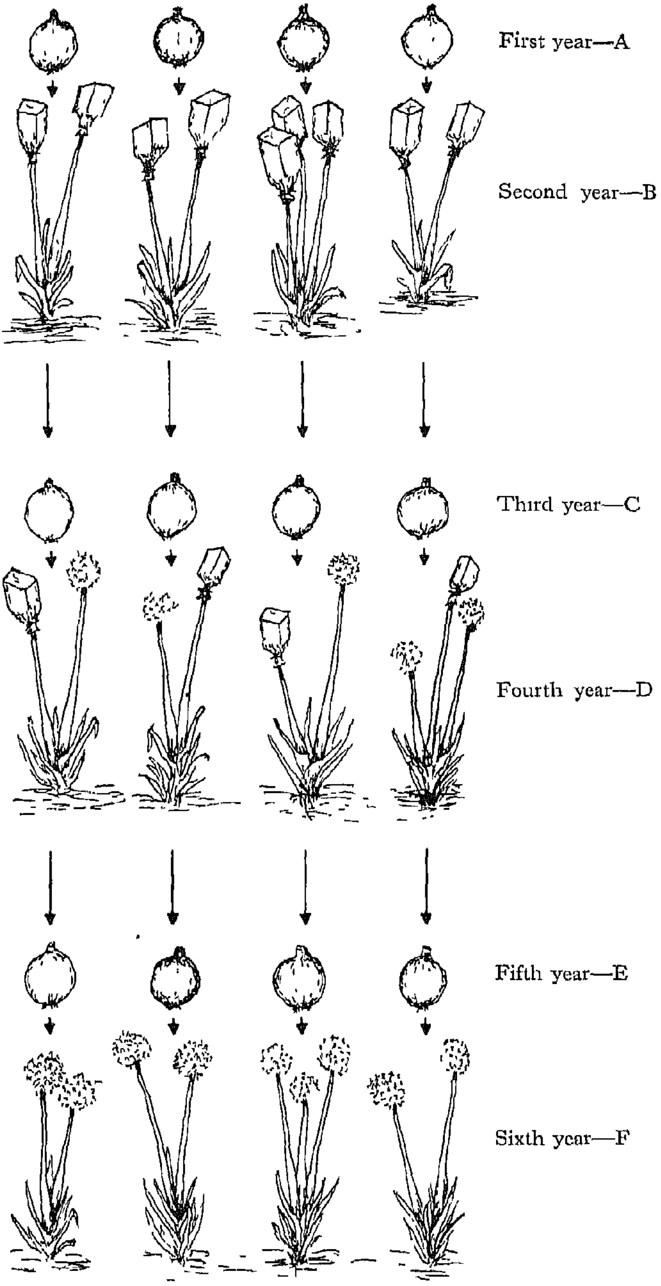

FIG. 9.—Onion improvement by selfing and massing.

A—Select about 100 bulbs of the desired type; B—Self one or more umbels per plant—*see* text for method. Each selfed plant initiates a separate line; C—Grow bulbs of each line separately, discarding poor lines and keeping 15 to 20 bulbs of each of at least 25 of the best lines; D—Self one umbel of each plant and allow the others to undergo open pollination. Mass open-pollinated seed and increase for commercial production; E—Repeat operations of third year; F—All open pollination—intermingle to get maximum amount of crossing among the 25 or more lines. Use the seed as foundation seed.

practical purposes it is best not to inbreed for more than two generations, because, as a rule, the plants become greatly weakened thereafter and will not produce a large quantity of seed.

Fifth Year: Grow separately the progenies that were selfed in the fourth year, and again select for open-pollination the best bulbs from at least 25 unrelated lines.

Sixth Year: Group all selections and plant them in the field or in a large cage, so that the maximum amount of crossing between unrelated lines will occur. Mass the seed and increase by open-pollination for commercial production.

After a desired type has been established, it can be maintained by selecting bulbs and massing for increase in screen cages or in the open under well-isolated conditions.

INBREEDING

In any onion improvement programme, a considerable amount of inbreeding or selfing is necessary. H. A. Jones & Davis (1944) showed that, accompanying inbreeding, there is, in general, a gradual loss of vigour, and that the chances of obtaining improved cultivars from inbreeding alone are rather remote. The losses that can be expected from the first to the sixth generations of inbreeding are shown in Table IX. No doubt the rate of loss indicated would have been more regular if more lines had been available for comparison. After three generations of inbreeding, many of the lines failed to produce seed, or did not survive in storage, because of their weakened condition.

While the chances of obtaining better commercial cultivars by inbreeding are relatively remote, there are notable exceptions. 'Excel', for example, which has been a very popular short-day onion for many years, is a first-generation inbred from 'Yellow Bermuda'. In the production of hybrid seed, however, inbreeding becomes an integral part of the programme. Selfing or inbreeding can be accomplished by several different methods.

TABLE IX
REDUCTIONS IN YIELD OBTAINED FROM INBREEDING ONIONS

(H. A. Jones & Davis, 1944)

Generations inbred (No.)	Lines compared (No.)	Bulb weight compared with commercial strain (%)
0		100
1	25	82·6
2	45	78·2
3	22	72·0
4	11	70·4
5	14	72·0
6	6	49·0

TECHNIQUES OF POLLINATION

Where rain is not expected during the pollinating season, the umbels can be covered with either one- or two-pound paper bags as soon as the first flower opens. Bags sealed with waterproof glue should be used. The bags are tapped vigorously once each day to circulate the pollen—usually in the afternoon when the pollen is dry. Pollination is facilitated if flowers are crowded in the bag. If the umbels are small, two or three from the same plant can be put inside one bag. This rather inexpensive method of selfing is used only when small quantities of seed are needed. Where strong winds prevail, it may be advisable to plant the onions between rows of maize, sunflowers, or other windbreaks, and to tie the seed-stems to stakes to prevent their breaking.

If a maximum amount of selfed seed is desired from each plant, the umbels should be enclosed in a small pollination cage made either of cloth or metal screen (Pl. 15(*a*)). The cloth cage is usually a cheesecloth sleeve fitted over a wire frame. The sleeve is closed by tying at the top; the cage is placed over the umbels to be selfed, and the whole is then wired or tied to a stake. Flies are put in the cage, and the cloth is finally tied firmly about the seed-stems below the cage.

Although metal-screen cages are rather costly and require considerable storage space, they provide good aeration, and usually excellent sets of seed are obtained in them. The screen portion is commonly about 8 to 10 in. in diameter and 10 to 12 in. long. A 20-mesh screen is preferred (i.e. 20 meshes per in.), and a detachable cloth sleeve is wired to the bottom of the cage. After umbels have been put in the cage, the cloth is tied tightly about the flower-stems below the cage, to prevent the escape of the flies. A solid metal strip, built into the screen part of these cages, has an opening, covered by a sliding or swinging door, through which flies can be added. Regardless of the type of cage, the flowers should not be allowed to come in contact with it, as the stigmas may protrude through the screen or cloth and become contaminated with foreign pollen carried by visiting insects.

Blow-flies are excellent pollinators, as they go from flower to flower, feeding on the nectar in the axils of the three inner stamens. They can be trapped in the open and used as pollinators if conditions are such that they are not contaminated with foreign pollen. A very good trap, shown in Pl. 15(*b*), has the bottom portion, which encloses the bait, made of wooden strips which are so spaced that flies can enter but larger animals cannot take the bait. Refuse of various kinds can be used to attract the flies; fish heads and beef lungs are excellent. The trapped flies, which gradually migrate towards the top of the screen, may be introduced to the pollination cages by means of transfer cages (Pl. 15(*a*)). If the corks are removed from the top of the trap and the bottom of the transfer cage, the flies move readily from one into the other. Wrapping a black cloth around the trap will speed their exit, as flies move towards the light. The number of flies used per cage depends upon the number of open flowers; if too many flies are added, they will die from lack of food; if too few are added, they will not do a satisfactory job of pollination. Under ideal conditions the same flies remain active in the pollination cages for two to three weeks, but during periods of excessively high temperatures their mortality rate is high and they may need to be replenished every day or two.

In certain localities, and at certain times of the year, trapped flies cannot be used because of the danger of contamination with foreign pollen. Consequently it is necessary to grow pollen-free flies under controlled conditions. This is done by placing beef lungs, or other meat, upon which the blow-flies will lay their eggs, on the top of a table which is so covered that the hatching maggots will be protected from the hot sun and rain. The maggots hatch within a few days, feed on the meat, and, when mature, wander about to find a place to pupate. The table top can be so designed that the maggots will be guided into buckets or boxes of sand, where they will pupate. The sand should be prepared by passing through a screen of sufficiently small mesh, so that, later, the pupae may be separated from it by re-screening. When adults begin to hatch, the pupae are put into the small transfer cages and, when emergence is complete, the flies are put into the pollination cages. Some breeders prefer to put the pupae directly in the pollination cage, where the adult flies will emerge. The pupae can be stored at about 7° to 8°C. for 3 to 4 weeks or more, and used when needed.

Walz (1951) described a method of raising the greenbottle fly on dog biscuits (Milk Bone Small Size Dog Biscuits manufactured by the National Biscuit Company, U.S.A.) in the greenhouse or laboratory without an accompanying disagreeable odour. A colony is started by cageing wild flies and feeding them on powdered milk and moist dog biscuits. Three-and-one-half dog biscuits are placed in a 50 ml. beaker filled with water, and left in the cage for 24 hours. After the flies deposit their eggs on the dog biscuits, the mass of eggs and biscuits is placed on top of the larval food, which is prepared as follows: dog biscuits are placed in a gallon jar to a depth of about 5 cm., covered with water, and allowed to stand until soaked through, after which the excess water is poured off. A fine wire screen is used to confine the maggots to the jars. If the population of maggots is too high for the available food, additional moist biscuits are added to a depth of 5 cm. at a time. After the maggots have fed for 6 to 7 days at 26° to 27°C., coarse sawdust is placed on top of the mixture as a medium for pupation. Following pupation, the sawdust containing the pupae is poured out and placed in cages, where the flies emerge.

After pollination has been completed, the cages are removed from the onion umbels. Seed is usually harvested when about one-quarter of the capsules have dehisced. Seed-heads from individual plants are kept separate, and then placed in paper or cloth bags to dry. Thrashing is best done on hot, bright days, the seed being rubbed or tramped out and the chaff and seed then dumped in water, where the chaff and light seeds float off. After three or four changes of water, the seed is placed on paper towelling to dry. When *thoroughly dry* it is packaged, all pertinent information regarding it being entered on the packet.

King (1961) has shown that the pollen of *A. cepa* may be freeze-dried and stored at room temperature for many weeks without losing its ability to germinate. This method of preservation might well facilitate experimental breeding where limited supplies of pollen are available, or where the cultivars to be crossed flower at different times. King shipped two samples of freeze-dried *A. cepa* pollen around the world in a package weighing less than 2 oz. The pollen had been stored for several weeks before shipping, and was en route for 33 days. There was no apparent loss of viability as a result of this treatment.

PRODUCTION OF HYBRID ONION SEED

Although seed of the open-pollinated, or 'fixed', varieties will continue to be used for a long time, the advantages of hybrid onions are becoming more widely recognized by growers and breeders throughout the world. Most of the hybrid onions of today can be traced back to the male-sterile 'Italian Red 13–53' plant described in the preceding chapter. As no functional pollen is produced by 13–53, it cannot be selfed (Pl. 16). It does, however, produce an abundance of small head-sets, i.e. small bulbs mixed among the flowers in the umbel, and these have served as a means of propagation since its discovery in 1925 (cf. p. 74). When 13–53 is out-crossed, it sets an abundance of seed; thus hybrids can be produced by crossing 13–53 with lines having functional pollen. One such hybrid, called 'California Hybrid Red No. 1' (Pl. 17(*a*)), which resulted from a cross between 13–53 and 'Lord Howe Island', was released. But it is no longer being produced, because of the great difficulty of keeping the vegetatively reproduced 13–53 free from the yellow dwarf virus.

Another method of producing hybrid seed has been found which avoids this difficulty: instead of perpetuating the male-sterile character by head-sets, this character is transmitted through the seed in a unique manner (as described in Chapter VI). For the production of hybrids by this method it is necessary to carry along three lines. Breeders refer to these as A, B, and C lines. The female or A line (*S ms ms*) is male-sterile and produces the hybrid seed. The B line (*N ms ms*), which is necessary to maintain the A line, is genetically similar to it except that it produces pollen. A third, genetically dissimilar or C line (*N Ms Ms*), is used to cross with the female line, for the production of hybrid seed

(Chapter VI). Although the terms 'female' and 'male', referring respectively to male-sterile and pollen-producing lines, are not botanically correct, they are widely used by onion breeders and so are employed here.

SECURING PARENT LINES

In many countries it may be difficult to obtain female plants with which to start a breeding programme. The development of A and B lines is a costly and time-consuming procedure and, as a rule, they cannot be purchased but must be obtained from a public supply, such as a state experiment station, or have to be developed independently. Fortunately, hybrid seed is widely available and, if necessary, can be used to get a start. If the hybrid seed has been obtained by crossing A and B lines, then all of the F_1 plants will be female. If the hybrid seed has been obtained by crossing A and C lines, then all of the F_1 plants will be fertile but, when selfed, one-fourth of the F_2 plants will be female. Any of these female plants can be used to cross with selected plants to determine if they carry the male-sterility gene. If the progeny from a selected plant and a female plant are all male-sterile (at least ten, and preferably more, progeny should be raised), then the selected plant can be considered as probably of the *ms ms* genotype. Seed from selfing this selected plant forms the B line (*N ms ms*). The F_1 progeny from the test cross, after back-crossing four or five times to the B line, will be genetically almost identical with the latter, except that it is male-sterile: this will be the A line (*S ms ms*). Fortunately, the male-sterility gene is widespread, having been found in most of the important American cultivars (Little *et al.*, 1946), and also in those from many other parts of the world. E. W. Davis (1957) tested onions from England, France, India, Japan, Korea, the Netherlands, New Zealand, Russia, Syria, Turkey, and the Republic of South Africa, for the presence of the *ms* gene. Cultivars from all of these countries except the Republic of South Africa had the *ms* gene present. In this deviating case, however, only one bulb was tested.

In a number of instances, female plants have been found in commercial seed fields of standard cultivars. Peterson & Foskett (1953), in the U.S.A., found 0·96 per cent of female plants in a seed field of 'Scott County Globe' onions. Kobabe (1958), in Germany, found female plants in two seed fields of 'Zittauer Gelbe'; one field had 1·0 per cent of females, the other 2·9 per cent, but he found only one female plant in several large fields of 'Stuttgarter Riesen'. Banga & Petiet (1958), in the Netherlands, report finding 92 female plants in commercial seed fields of the two Dutch cultivars, Primeur and Wijbo. Makarov (1960), in the U.S.S.R., found female plants in the cultivar Arzamas, and Yen (1959) demonstrated the presence of *S* and *ms* in the cultivar Pukekohe Longkeeper in New Zealand. If female plants are found in commercial fields, they can be used to test for fertile plants carrying the *ms* gene. The procedure is similar to that outlined above, except that little back-crossing is necessary as the A and B lines are genetically similar at the start.

After the A and B lines have been secured, the task of producing hybrids is only partly accomplished, because it is necessary to develop a second male line (C line) to cross with the female line for the production of hybrid seed. Such male lines are usually inbred for several generations, to get uniformity. Those that appear to be most promising are planted in small crossing blocks with different A lines—either in cages or in the open. A ratio of about four female plants to one male plant is used. The F_1 experimental hybrids are planted in observation tests. Those that survive the observation tests are then planted in replicated trials and in small field-tests before the best are chosen for commercial production.

HANDLING A, B, AND C LINES IN CAGES

When satisfactory A, B, and C lines have been developed, as indicated by their ability to produce a desirable hybrid, they should at first be increased in cages and not in the open. Every precaution must be taken to avoid genetic and mechanical mixtures, of both seed and bulbs, in all the processes of growing and handling. It is especially important to avoid getting the B line (*N ms ms*) contaminated with the *Ms* gene: its presence in the B line cannot be detected, but it will cause varying numbers of fertiles to appear in the A line in later generations. The presence of a large number of these pollen-bearing plants in the A line in a seed field will make rogueing costly, and moreover excessive rogueing reduces the seed yield. If the seed field is not rogued, the uniformity we associate with hybrids will be lacking. Careless techniques will soon ruin a hybrid programme—hence the necessity to be constantly on the alert to avoid mixtures. It seems advisable, when growing mother bulbs for increase, to plant all A lines in one section of the nursery, B lines in another section, and C lines in still another, rather than have them intermingled.

Small lots of stock seed of A and B lines should be increased only in insect-proof cages. Saran or Lumite plastic screen, 20 × 20 mesh per in., is satisfactory, and excludes the smaller insects which are capable of carrying contaminating pollen (Pl. 17(*b*)). Steel or aluminium pipe- or rod-frames are ordinarily used to support the screen. These are made in panels which are wired together when used. The screens should be equipped with a heavy-duty zipper at one corner-post, to allow easy entrance and exit. In measuring the screen, an extra foot should be added to the height, so that the bottom can be extended and buried in the soil. A 10 × 20 × 6 ft cage will accommodate four rows of bulbs, leaving a space of 2 ft between the rows. This size of cage should produce from 2 to 5 lb. of seed, depending upon the lines involved and the growing conditions. About equal numbers of A- and B-line bulbs should be planted in the cages.

Precautions should be taken to prevent the umbels from touching the screen or cloth, as this would allow the stigmas to protrude and become contaminated with foreign pollen carried by visiting insects. This danger can be avoided by driving in 5-ft stakes at the end of each row of plants, and at intervals within each row, and then weaving heavy twine back and forth, from stake to stake, so that the seed-stalks are held in an upright position.

A nucleus box containing about 3 lb. of bees (Pl. 17(*b*)), complete with comb, brood, and queen, should be placed in each cage. If there is danger of introducing foreign pollen with the bees, they should be placed in the cage about 3 days before flowering begins. A 10 per cent sugar solution in each cage will provide adequate food for the colony. Enamelled tin cans of about 500 ml. capacity, equipped with burlap wicks, make the sugar solution readily available. Water should always be accessible. If a colony becomes greatly weakened, it should be replaced.

Despite precautions, occasional contamination is bound to occur, and this necessitates careful rogueing within the cages. Rogueing, which should be done each morning before the anthers have dehisced, involves the removal of pollen-bearing plants from the A line, of pollen-sterile plants from the B line, and of all other off-type plants. In rogueing, precautions should be taken to prevent transference of pollen on the hands or clothing from cage to cage.

FIRST INCREASE OF A AND B LINES IN THE OPEN

Because of excessive cost, it is usually not possible to produce sufficient A-line seed in cages to plant the commercial seed fields. For large increases, A and B lines must be planted together in the open. 'Increase blocks' of an acre or more in size are preferable, and these should be at least two miles from any other onion seed field. Experience indicates that, the smaller the increase block is, the higher will be the percentage of contamination from foreign pollen. Regardless of the size of block and degree of isolation, some contamination is bound to occur when A lines and B lines are increased in the open. An abundance of pollen from the B line helps to prevent or reduce contamination from outside sources. To obtain a good supply of pollen, the A- and B-line bulbs should be planted in a ratio of 1 : 1, with several rows of the B line planted around the outside of the field. Daily rogueing during the flowering season is essential.

If satisfactory quantities of seed from A and B lines are realized in the first uncaged increase, enough stock seed of the A line may be available to make a particular F_1 hybrid for 3 or 4 years, depending upon the amount of hybrid seed needed. Otherwise, a second increase in the open will be required, and the same precautions should be applied in making it. Seed from a second increase in the open should be used only for the production of F_1 hybrids, and not for further increase. This emphasizes the need of carrying on a stock-seed programme simultaneously under cages and in the open. C lines, like the A and B lines, should be increased first under cages and then in the open.

INCORPORATING NEW CHARACTERS

When a new character is to be incorporated into a hybrid, it is usually necessary to resort to emasculation and then crossing in the B or C line. The usual method is to remove the open flowers on an umbel in the early days of flowering, until a considerable number open each day. At first only a few flowers on the umbel open daily, but the number increases until full bloom, when 50 or more may open in a single day. When blossoming is at its peak, open flowers are no longer removed, but are emasculated and used for crossing. In hot weather, flowers open quickly and the anthers soon dehisce, so that it is necessary to examine the umbels several times each day. When sufficient flowers have been emasculated, the remaining buds of the umbel are removed. The emasculated flowers are gathered together in a cluster and tied in an upright position by a thread or string. The umbel is then enclosed in a small cheesecloth or screen cage, the same as that used for selfing. A flower-stalk from the pollen parent, which has been kept covered to prevent contamination, is cut off near the base, and the cut end is stood in water, the umbel being placed slightly below the flowers that have been emasculated. Flies are then put into the cage to do the pollinating which, as a rule, is completed after about 4 or 5 days. When this procedure is followed, excellent sets of seed are obtained.

SPECIES HYBRIDS

A number of crosses have been made between the species *Allium cepa* and *A. fistulosum*. The latter species does not form bulbs, and the hybrids, which bulb only slightly, are useful as green bunching onions. Colchicine is used to convert the diploid hybrids into amphidiploids, which are more vigorous and partially fertile—the diploids of this cross are almost completely sterile. The method used to double the chromosomes is that devised by Wellensiek (1947) for wheat-rye hybrids. F_1 seedlings of the cross *A. cepa* × *A. fistulosum* are allowed to grow normally until the diameter in the sheath region is about that of a lead pencil. The plants are then pulled, the roots washed, and the seedlings alternated for several days, for periods of about 12 hours each, in a 0·05 per cent colchicine solution and running tap-water. Only the roots are immersed in the solution. Doubling of the chromosomes occurs in cells that later form parts of the inflorescence. Those segments of the inflorescence that are so doubled will set seed. A single inflorescence may have from one to several fertile segments.

M. G. Toole & Clarke (1946) secured autotetraploids in both *Allium cepa* and *A. fistulosum* by treating germinating seeds with 0·1 and 0·5 per cent aqueous solutions of colchicine for 3 hours. Colchicine is toxic, and less killing occurred in the 0·1 per cent treatment than in the 0·5 per cent one, and also when the treatment was applied to seedlings with roots less than 0·5 mm. long. The very young seedling stage seemed to be the best time for getting colchicine into the apex of the stem.

A highly pink-root-resistant tetraploid called 'Beltsville Bunching' was released to the seedsmen in 1950 by the United States Department of Agriculture and the California Agricultural Experiment Station. It is a natural amphidiploid that was found growing among other F_1 species-hybrids of *A. cepa* 'White Portugal' and a bunching-type of *A. fistulosum*. It is very popular in certain parts of the United States as a home garden and market garden cultivar. In addition to being resistant to pink-root, it is highly resistant to yellow dwarf and smut. It is very vigorous in vegetative growth, but a rather poor seeder.

BREEDING FOR DISEASE AND INSECT RESISTANCE

Resistance genes have been found for a number of diseases that affect the onion crop, and work is under way at several institutions to develop onions that are resistant to one or more diseases.

PINK-ROOT

Porter & Jones (1933), working at Davis, California, found that certain strains of *Allium fistulosum* and the cultivar Sweet Spanish were resistant to the pink-root fungus, *Pyrenochaeta terrestris* (Hans.) Gorenz, J. C. Walker, & Larson. A resistant selection called 'Spanish No. 2' was released by the California Agricultural Experiment Station to seedsmen in 1939. Although this cultivar never became popular commercially, it is being used in breeding programmes as a source of resistance.

A number of short-day, pink-root-resistant cultivars (Excel, L36, L365, Eclipse, Early Crystal 281, and Texas Hybrid 28), developed for the southwestern United States (Perry & Jones, 1955), give high yields on heavily-infested soil in southern Texas, where susceptible types fail to produce marketable bulbs (Pl. 18(*a*)). The sources of resistance for the development of these cultivars were plants that were found in the cultivars Crystal Wax and Yellow Bermuda. Screening for resistance was done in the field in southern Texas, in soil that was uniformly infested with the pink-root fungus.

Gorenz *et al.* (1949) developed a method for screening seedlings in the greenhouse under controlled conditions. Seed is sown in pans of inoculated fine silica sand that is held at 24°C. A moderately pathogenic strain of pink-root fungus is used. After 30 days, resistant seedlings are selected and planted in the greenhouse and, when sufficiently large, set in the field for bulb and seed production. Resistant plants have been isolated in this way from many commercial cultivars and breeding lines.

Many races of the pink-root organism exist, and these differ in pathogenicity. A cultivar which is resistant to one race may not be resistant to other races of the fungus.

FUSARIUM

Kehr *et al.* (1962) report that some resistance to the fungus *Fusarium oxysporum* f. sp. *cepae*[1] is found in breeding lines B 2264 and TEG 951. Both of these lines are now being used in the production of commercial hybrids. Also resistant was a selection of 'Yellow Sweet Spanish'. Resistance to *Fusarium* decreased as the temperatures in sand cultures were increased above 24°C.

DOWNY MILDEW

Downy mildew, caused by the fungus *Peronospora destructor* (Berk.) Casp., is one of the most destructive diseases of the onion seed crop and may also cause heavy losses in the bulb crop. In the male-sterile clonal line 13–53, the seed-stems are immune to mildew and the leaves are highly resistant. 'Calred', developed from 13–53 and 'Lord Howe Island', has resistant seed-stems, but the leaves are more susceptible than those of 13–53. The greatest drawbacks in breeding for mildew resistance are the sporadic occurrence of mildew epidemics and our inability to culture the fungus on artificial media.

Yarwood (1943) has helped to overcome some of these difficulties by injecting a spore suspension into the bulbs, leaves, and seed-stems. Using a hypodermic syringe, bulbs varying in size from 3 to 100 gm. were injected at their centre with a trace to about 1 ml. of spore suspension. The syringe needle was inserted to the middle of the bulb, withdrawn about 1 mm., and the spore suspension was then forced in between the leaf-bases. By this injection method, systemically infected plants have been produced which were similar to those that had been infected naturally. The inoculated bulbs grow as rapidly as uninoculated bulbs, and usually in about 2 weeks under greenhouse conditions produce leaves that are large enough for sporulation.

PURPLE BLOTCH

Onions such as 'Yellow Globe Danvers' and 'Red Creole', that have a good covering of wax or bloom on the foliage and seed-stems, are more resistant to the purple-blotch fungus (*Alternaria porri* (Ell.) Cif.) than are such cultivars as Yellow Bermuda, Early Grano, and Sweet Spanish, which have less of this wax excretion. Under humid conditions, where purple blotch is usually prevalent, it is best to grow the resistant types.

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[1] f. sp. indicates *forma specialis* or form species, i.e. clones of *Fusarium oxysporum* attacking *Allium cepa*.

ONION SMUT

So far as is known, no high degree of resistance to the smut fungus (*Urocystis cepulae* Frost) exists in cultivars of *A. cepa*. However, the Welsh onion, *A. fistulosum*, is highly resistant. An F_1 hybrid between the two species is intermediate in resistance, but sterile. The natural amphidiploid 'Beltsville Bunching' has considerable resistance.

BLACK MOULD

According to Hatfield *et al.* (1948), the cultivar Australian Brown seems to be more severely attacked by black-mould fungus (*Aspergillus niger* Tiegh.) than are most other cultivars and, in general, coloured cultivars seem to be more susceptible than white ones. It appears that the same chemical substances which give resistance to smudge, and to a certain extent to neck-rot, may be the ones which make coloured cultivars susceptible to black mould. Pungency is not thought to be important in determining the severity of infection.

NECK-ROT

One of the main sources of storage loss is neck-rot, caused chiefly by *Botrytis allii* Munn. Owen *et al.* (1950) found that mild-flavoured cultivars in each colour group (red, yellow, white) had consistently more neck-rot than the strongly pungent ones. In the mild-flavoured cultivars, the difference in the amount of disease between white or coloured plants was not significant. In pungent cultivars, the whites suffered considerably more from disease than the coloured ones. The neck-rot organism invades the onion bulb primarily through dead or senescent tissue of the neck, or through wounds in the bulb. It is sensitive to the phenolic compounds of the outer coloured scales, but these antibiotic substances are found in smaller quantities in the dead neck tissue than in the bulb proper. Once the fungus has penetrated past the outer scales of the bulb, it becomes associated with the pungent antibiotics of the fleshy scales, and these undoubtedly restrict its growth. Evidence seems to indicate that pungency is more important than colour in giving resistance to neck-rot.

SMUDGE

In coloured cultivars, there is usually more resistance to the smudge fungus (*Colletotrichum circinans* (Berk.) Vogl.) in the outer, dry, coloured scales of the bulb than in the inner fleshy scales. However, in coloured cultivars that lose their outer scales easily, the inner fleshy scales become infected about as easily as they do in the white cultivars. For providing resistance to smudge, the antibiotics associated with dry scale colour seem to be much more important than the antibiotics associated with pungency.

THRIPS RESISTANCE

Cultivars of onions differ considerably in their resistance to thrips (H. A. Jones *et al.*, 1934). This resistance may be determined by certain morphological characters which help to hold the thrips population to a minimum, and perhaps anatomical and physiological characters may help the plant to withstand injury. In 'White Persian' (Pl. 18(*b*)), the shape of the leaves is probably of importance in restricting the population of thrips. In most cultivars the leaves have a flat side: in opposing leaves these sides are face to face, and the young leaves are closely pressed together, so that the larvae between these leaves are protected against predators and adverse weather conditions. In 'White Persian', on the other hand, the leaves are almost circular in cross-section, and the wide angle between the two innermost leaves, especially in the young plant, restricts the thrips population by reducing the area of protection to a minimum.

Still another character which is probably of some importance in 'White Persian' is the vertical distance between the leaf-blades, each new leaf extending its sheath farther beyond the one encircling it than in other known cultivars. This habit of growth produces an extremely long sheath column. If commercial cultivars of onions had such leaf characters, the thrips population per plant would be reduced to a minimum, and it would be possible to secure more efficient control by spraying or dusting. The glossy foliage character of 'White Persian' is also associated with a low thrips population. Although highly resistant to thrips, these glossy types are extremely susceptible to tip-burn, purple blotch, and downy mildew, and accordingly their cultivation is rather hazardous. New insecticides give good control of thrips, but the need for thrips-resistant cultivars still exists and offers a fruitful field for research.

The original 'White Persian' onion, brought to the United States as a plant introduction from Iran, has been lost. It is hoped that it can again be found, as it would be of great value for breeding purposes.

VIII

ADAPTATION OF CULTIVARS

ALTHOUGH *Allium cepa* is not known today as a wild plant, most authorities agree that it once grew wild somewhere between western China and the deserts lying east of the Caspian Sea. For thousands of years the onion was probably confined to this geographical region, and it was apparently here that it was gradually brought into cultivation. Most of the characters with which this species is endowed presumably had their origin in this same region (30° or more N. latitude) and have been carried in the germ-plasm ever since.

Although the onion is one of the oldest cultivated crops, its period of domestication has been brief compared with the time during which the species evolved. To account for the evolution of present-day cultivars, we must assume that the forces which caused changes in the past are still operating—that mutations and the recombination of hereditary units continue to give rise to new characters. Under cultivation, however, many of the new characters that would have been lost under the rigorous selection of nature can be maintained by man if they suit his fancy. Thus, in some ways at least, the *Allium cepa* of today is a more varied species than it ever was in the wild. As man migrated to new countries and new climates, only a few of the onions which he took with him performed satisfactorily, so these were saved for reproduction and further selection. Thus, through migration to many parts of the world and by countless generations of selection, the present-day cultivars were evolved. They are indeed a diverse group, adapted to many uses and grown in many climates—in fact, in almost all inhabited parts of the world except where tropical conditions prevail.

Experience has shown that cultivars which are adapted to the onion-growing districts of the northern United States will not mature bulbs properly in the South; and conversely, cultivars that are adapted to the southern United States, when planted in the North, will mature bulbs too early, and which are too small, for a profitable crop. Likewise, in certain areas, onions that are grown for bulbs are prone to bolt, making the crop less valuable for market. Successful bulb production in any district, then, depends upon selecting cultivars that will grow and bulb satisfactorily under the conditions imposed by the specific environment. But, as most onion growers know, a cultivar does not always perform in the same way year after year, even in a district for which it was developed.

To explain the marked adaptation of cultivars to specific environments, and to understand the variations that may be shown from year to year in one locality, we must identify those environmental factors which most strongly affect the development of the onion plant. We do not understand the parts played by all aspects of the environment, but we do know that photoperiod and temperature seem to be the most important. Interacting with photoperiod and temperature is an internal factor —plant size. As the photoperiodic stimulus is received by the leaves, some foliage must be present for the plant to respond to day-length, but whether it is in leaf or dormant (bulb), the onion may respond to temperature. Sensitivity to photoperiod or temperature, especially the latter, may increase markedly as the small onion plant increases in size.

It may be helpful here to recall a point which was emphasized in the chapter on morphology—that the young plant consists of a stem which produces a succession of foliage leaves at its apex, and that this type of growth (with neither bulbing nor bolting) may continue indefinitely. In fact, it usually does continue until the external environment stimulates the leaves to form a bulb or the stem apex to differentiate into a flower-stalk. Bulbing and bolting may occur separately or together; although some interaction may take place between these processes, they are most conveniently dealt with independently. In this chapter we shall consider the effect of the various environmental factors on the bulb crop. Effects of environmental factors on sets, transplants, and on the seed crops are discussed in Chapters IX, X, and XIII, respectively.

BULBING

PHOTOPERIOD

When grown under very short photoperiods that are produced artificially, onion plants form new leaves indefinitely, without bulbing. At most latitudes, however, the days eventually reach the critical length needed for bulb formation. At ordinary temperatures this length varies from about 12 to 16 hours, depending on the cultivar.

The response of a number of European and American onion cultivars to length-of-day was studied by Magruder & Allard (1937). They found that cultivars differed markedly in the minimum photoperiod required for bulb formation, as well as in the rate and uniformity of bulb formation at day-lengths that were above the minimum for the cultivar. The photoperiod that was necessary to produce 100 per cent normal bulbs was longer than that required to produce the earliest-maturing normal bulbs—indicating that most cultivars are not homozygous in their response to day-length.

The day-length of any place is determined by its latitude and the time of year. At the Equator there is little difference in day-length in summer and winter; the day-length is always near 12 hours. As the latitude increases, from the Equator towards the poles, the summer days become longer and the winter days shorter, until at the poles the sun never sets in summer nor rises in winter. At high latitudes, where the days of spring and early summer are relatively long, only cultivars requiring quite long days for bulbing can make sufficient growth, before bulbing, to be productive. As many European countries lie at latitudes that are considerably farther north than the United States, cultivars from the United States usually mature too early in these countries to give maximum yields. Conversely, cultivars from these northern European countries require very long days to bulb, and even in the northern United States, the longest days of summer may be too short for them to mature properly. A cultivar is more likely to be adapted to different districts in the same latitude, because of uniformity in the length of day, than to districts of similar climate in different latitudes.

The relation of bulbing to photoperiod has helped to explain one of the problems that long perplexed the onion seed growers of the United States. Before 1946, most of the 'Crystal Wax' and 'Yellow Bermuda' seed that was used for the production of the early crop in southern Texas was imported from the Canary Islands, located at about 28° N. latitude. The onion districts of south Texas are at about the same latitude as the Canary Islands, but the growers in Texas claimed that the bulbs which were grown from domestic seed matured later than bulbs grown from Canary Island seed, and there seemed to be some justification for their claims. Before 1946, most of the mother bulbs of these cultivars were selected for seed production at higher latitudes, where the crop was grown in the spring and where the days were relatively long. Under these conditions, bulbing was hastened and mostly small onions were produced. As these cultivars were not homozygous for time of maturity, a few plants matured somewhat later and consequently made larger bulbs. These larger bulbs were thought to be more vigorous, and were usually selected for increase. When the seed from these was planted in southern Texas under short-day conditions, the bulbs matured later than those of the parent cultivar. It was only when mother bulbs were selected under short-day conditions, similar to those of the commercial crop area, that earliness was maintained. At present the seed of most of the Bermuda-type onions used in the United States is grown domestically. Not only has earliness been maintained, but selections such as 'Excel', that mature about 10 days earlier than its 'Yellow Bermuda' parent, are now widely grown.

The influence of day-length on size of bulb is easily demonstrated by comparing plantings at different latitudes. In the United States, for example, the 'White Grano', a winter crop in the south, is planted in the autumn, develops a large plant during the winter, and forms bulbs from 3 to 4 in. in diameter in the spring. When this cultivar is grown as a spring crop at 44° N. latitude, the day-length which it requires for bulbing is usually exceeded before the seed is planted, so that bulbing occurs as soon as the minimum temperature requirements are met. The plants at this time are usually still small, and consequently small but well-matured bulbs are formed (Pl. 19(*a*)).

This ability to form large bulbs as a winter crop and small, well-matured bulbs as a summer crop, is used to advantage with certain cultivars. 'Eclipse' can thus be grown as a large onion for shipping in the southern United States, and as a small onion for pickling in the north. Of course, pickling-sized onions can also be produced in southern districts by planting the crop so that the plants will still be small when both photoperiod and temperatures exceed the minimum required for bulbing. A number of cultivars are used to serve this dual purpose.

Large bulbs of short-day cultivars can be produced at high latitudes by setting transplants in the field instead of direct seeding, so that the plants are much larger than seeded plants when conditions favour bulb development. While it is possible to manipulate the crop so that short-day cultivars can be made to produce acceptable bulbs under long-day conditions, it is impossible to produce acceptable bulbs of long-day types under short-day conditions. This is illustrated in Pl. 19(*b*), which shows Southport White Globe, a long-day cultivar, growing at latitude 33° N. The temperature conditions were extremely high, and bulbing was initiated and some swelling occurred; but the days were so short that the necks remained stiff and upright and the bulbs did not mature.

Day-length plays such an important role in the adaptation of onion cultivars, that the terms 'short-day types' and 'long-day types', referring to the suitability of certain cultivars for low or high latitudes, have come into common use. All cultivars of the common onion are long-day plants with respect to bulb formation, i.e. they bulb more readily as day-lengths increase. The 'short-day' cultivars are not short-day plants, but simply cultivars which bulb under relatively shorter days than many others. Also, like other plants that are responsive to day-length, onions are actually sensitive to the length of the dark period of the night rather than to the length of the day; they might more accurately be termed 'short-night' plants. By custom, however, we use the term 'long-day', and it introduces no error so long as we confine ourselves to the natural 24-hour day-and-night cycle.

TEMPERATURE

Although day-length seems to play the major role in the adaptation of onion cultivars, temperature also plays an important part. Other factors being equal, onions bulb more quickly at warm than at cool temperatures. In fact, temperature is probably so directly related to bulbing that a minimum photoperiod cannot be specified without also specifying the temperature.

Temperature conditions, in contrast to day-lengths, are never exactly alike, year after year, in the same district; consequently, onion cultivars cannot be expected to perform consistently, even though cultural practices are similar. Unless the effect of temperature is understood, one can easily draw erroneous conclusions about the performance of cultivars. Time of maturity is often important in commercial practice, because early onions often command a high price. A considerable portion of the world's crop is grown during the winter, and much of it is used for export or for shipment to domestic markets. Unusually cool winter weather may delay bulb maturity as much as 3 to 4 weeks; this results in competition with the normally later-maturing crop, causing market gluts and lower prices.

Thompson & Smith (1938) found that 'Ebenezer' onion plants, grown in a greenhouse at Ithaca, New York, under natural day-lengths plus supplementary light until 10 P.M., did not react in the same way under three different temperature treatments. The experiment was started on December 3rd, and by March 10th plants that had been grown at 50° to 60°F. showed no bulbing; those that had been grown at 60° to 70°F. had mature bulbs and the tops had fallen but were still green; and those that had been grown at 70° to 80°F. had mature bulbs and the tops now dead. High temperature alone, however, was not effective in causing bulbing, because plants that were grown without supplementary light at that season of the year failed to bulb at any of the above temperatures. These results show that bulbing is not determined by day-length alone, but by the interaction of day-length and temperature. These two components of the environment determine primarily the limits of adaptation of different cultivars.

The autumn-planted crop of onions develops at first under falling temperatures and shortening days; about December 21st in the northern hemisphere, and June 21st in the southern hemisphere, the days start to get longer, but temperatures usually continue to fall for some time, because more heat is radiated during the long night periods than is absorbed during the short days. If the weather is favourable, plants continue to grow throughout the winter, but bulbing will not start until the temperature-day-length combination exceeds the minimum requirement. If low temperatures prevail, maturity will be delayed. If temperatures suddenly greatly exceed the minimum, bulbing may be rapid and maturity hastened. Thus from year to year a considerable spread may occur in the maturity date of a given cultivar. Actually, we have no information on how widely cultivars differ in their temperature requirements for bulbing.

When onions are grown as a summer crop, temperature again plays an important role in determining the maturity date. Under conditions of extremely high temperatures, bulbs will mature early and yields may be reduced; at low temperatures, maturity is usually delayed, curing becomes difficult, and storage quality is often impaired.

Low temperatures at high altitudes may delay the bulbing of a cultivar well beyond the date that is usual in warm areas of similar latitude, for low temperatures enable cultivars with short-day requirements to develop considerable foliage before bulbing begins. This explains, at least in part, why short-day cultivars grown at high altitudes make bulbs of good size even under conditions of quite long days.

The onion district around Celaya, Mexico, presents an interesting study in the effects of length-of-day and temperature on bulbing. This district, at an altitude of about 5,000 ft, is near 19° N. latitude, so there is not much difference in length-of-day between the short days of winter and the long days of summer. The short-day cultivar Cojumatlán is about the only onion grown, and it has probably been grown there for many generations. It is a common sight to see fields of this large, white, attractive onion being harvested while adjoining fields are being transplanted. Bulbs mature well during the cool days of winter, as well as during the hot days of summer. This cultivar is able to grow and form a large plant, and bulb normally, while the days are getting shorter and the temperatures cooler—as well as when the days are getting longer and the temperatures warmer. The days never seem to get sufficiently long, or the temperatures sufficiently high, to hasten bulbing greatly, so that the plants always grow large enough to make bulbs of good size. Bolting is probably most prevalent in the winter and, no doubt, bulbing most rapid during the summer; but few data are available concerning these matters.

PLANT SIZE

It is perhaps under conditions such as those at Celaya—the lack of environmental factors strongly conducive to bulbing—that the size of the plant may have a considerable effect.

The size and age of the plant have long been known to affect its bulbing and time of maturity. When dry onion sets, transplants, and seed of the same cultivar, are planted at the same time, they start to bulb and mature in the order named. Age, size, or stored food—possibly all three—play some unknown part in triggering the mechanism that initiates bulbing. When large and small dry sets of the same age are planted at the same time, plants from the large sets mature first, indicating that the amount of stored food may play a definite role. Probably a mechanism similar to this operates in the Celaya area, the plants bulbing readily only after they have made considerable growth, so that bulb size is always satisfactory.

H. A. Jones (1930), working with the transplant onion crop, showed that the time of maturity was progressively delayed as plant spacing in the row was increased from 3 to 12 inches. Onion plants start bulbing sooner, and mature 3 to 4 weeks earlier, when they are grown crowded in the row for the production of dry sets, than when they are spaced for the production of large bulbs. Dry sets are produced from small plants, and plant size itself does not seem to inhibit in any way the onset of bulbing if photoperiod and temperature exceed the minimum requirements. Under conditions that were very favourable to bulbing, 'Red Creole' has been observed to bulb when it had developed only one leaf in addition to the cotyledon. The bulbs formed were about the size of the seed of the garden pea. They matured normally and had a distinct rest-period which was similar to that of large bulbs.

The influence of the environment on characteristics other than bulbing and bolting is discussed at some length by Magruder *et al.* (1941*a*), who cite a rather extensive bibliography.

NITROGEN NUTRITION

Scully *et al.* (1945) have shown that, when onion plants are subjected to photoperiods which are well above those that are critical for the cultivar, bulbing starts immediately; within the critical range, however, bulbing is somewhat slower, and the plant is more susceptible to the influence of other environmental factors. Thus, at photoperiods that were much above the critical range, nitrogen nutrition did not influence the bulbing response, but when plants were grown near the critical photoperiod, a deficient nitrogen supply had the same effect as lengthening the photoperiod, and a high nitrogen supply had the same effect as shortening the photoperiod. At critical photoperiods, then, a deficiency of nitrogen will hasten bulbing, and an excess of nitrogen will slow the bulbing process. The 'critical' photoperiod, as used here, refers to that day-length which is just sufficiently long to induce bulbing. At this critical day-length, changes in such factors as nutrition and temperature have their most decisive effect on bulbing.

BOLTING

The factors which influence bolting are of importance to the bulb grower because yield and quality are lowered by bolting. Photoperiod has little effect on the initiation of flowers; rather, bolting is induced almost entirely by cool temperatures. Both bulbs in storage and growing plants may be induced to bolt, but, in contrast to bulbing, size is of critical importance, for small bulbs or plants show little or no induction of flowering by cool temperatures.

The effect of cool temperatures on the bolting of bulb crops may be very pronounced, and in certain seasons losses due to bolting of the crop grown from dry sets, transplants, or seed, are quite severe. Thompson & Smith (1938) found that, when medium-sized sets of 'Ebenezer' and 'Red Wethersfield' were planted and grown in a greenhouse at 50° to 60°F., both cultivars bolted 100 per cent; at 60° to 70°F., bolting did not exceed 10 per cent; and at 70° to 80°F., there was no bolting at all.

Length-of-day had no effect on the percentage of bolters. The same cultivar will vary from season to season in the amount of bolting; a long, cool spring is usually accompanied by a high percentage of bolting, and a warm spring by a low percentage of bolting. Bolting of large sets is suppressed by storing at high temperatures (Chapter IX).

Bolting in the winter crop that is grown from transplants may be extensive—especially when plants are well fertilized and receive favourable growing weather in the autumn and winter, followed by several weeks of cool weather in early spring. Conversely, if growth is retarded because of low temperatures during the early part of the growing-season, and high temperatures prevail later in the season, very little or no bolting occurs. Growers must learn from experience the earliest 'safe' planting dates for the particular cultivars they grow, so that in most years bolting can be avoided.

Cultivars vary considerably in their susceptibility to bolting. Those with a tendency to bolt should be planted late, so that a small plant will be over-wintered. G. N. Davis & Jones (1944) reported the bolting behaviour of 23 cultivars that had been grown from transplants at Davis, California. When it was seeded on September 6th, 'White Sweet Spanish' produced 71 per cent bolters; but when it was seeded two months later, it produced only 2·6 per cent bolters. 'Italian Red' produced no bolters even with the early seeding.

Usually there is very little bolting in the direct-seeded spring crop in the northern United States. As a rule, low temperatures prevail only while the plants are small, and therefore do not cause bolting. In the western States, however, when 'Sweet Spanish' is grown, the percentage of bolting may be high if the crop is seeded early, and if rapid early growth is followed by a period of cool weather.

There is evidence that rapid bulb formation may suppress the emergence of inflorescences which have been initiated but have not yet elongated (Heath & Holdsworth, 1948). Thus, warm temperatures early in the growing-season may reduce bolting in two ways: by decreasing inflorescence initiation, and by favouring rapid bulbing. But whereas the role of temperature in inflorescence initiation is well-documented, we have few data on which to assess the importance of rapid bulbing in supressing bolting in commercial onion crops.

EVALUATING ADAPTATION IN NEW CULTIVARS

Because of the influence of the fluctuating environmental conditions on the growth of the onion plant as discussed above, one can understand why a cultivar does not perform exactly the same, year after year, in the same district. Most of the old-established onion-growing districts have cultivars that give a fairly satisfactory performance—a good crop most years, and occasionally one that is outstanding. However, there is a continuous search for something that is better; this is no less true for the onion than for other crops. Many new cultivars are being offered to the grower, and the number has greatly increased since the introduction of hybrids. In the United States, the U.S. Department of Agriculture with its National Onion Breeding Programme, several state agricultural institutions, and most of the large seed companies, are actively engaged in the development of better hybrids. Important onion-producing countries, such as Egypt, the Netherlands, and Japan, have extensive breeding programmes. In the years ahead, the evaluation of these new introductions will be of considerable importance.

Most of these new introductions will have been tested in small plots at several locations for a number of years before being released, and the conditions to which they will be adapted will usually be fairly well known. But the acid test for any new cultivar is whether it will 'stand up' under commercial production. A cultivar may look promising for several years and then suddenly disappear because of a weakness which showed up under certain environmental conditions. Even though a new cultivar appears to be outstanding the first year it is tested, it is best not to change over to it completely. New cultivars should be tested for at least 3 or 4 years, to determine whether they will perform satisfactorily in different seasons. A good method of testing introductions is to strip-plant them through a commercial field, so that they will get the same cultural treatment as the main crop.

Cultivars that do not seem to be adapted at first may give a good performance with a slight change in cultural practice. Thus, when 'Excel', a short-day onion that is usually grown as a winter crop, was first introduced, it was claimed to be from 7 to 10 days earlier than 'Yellow Bermuda', the cultivar from which it was selected. Because of this earliness, many growers assumed that it could be planted earlier, and the result was a high percentage of bolters. Growers in different districts soon found that there was a best time to plant to get a minimum of bolters and the maximum production of bulbs. Growers had a generally similar experience with the F_1 hybrid 'Granex'. This hybrid is very vigorous and makes rapid, early growth. Too early planting in many districts produced large plants which bolted excessively after overwintering. This was corrected by delaying the planting date.

The F_1 hybrid 'Early Harvest' was introduced by the United States Department of Agriculture to replace, to some extent, the crop grown from dry sets. When seed of 'Early Harvest' is planted at the same time as dry sets of 'Ebenezer', the bulbs mature at about the same time. The hybrid makes rapid early growth and, if planted early, the plant is fairly large before the minimum temperature and photoperiodic requirements are exceeded, and a bulb of good size is produced. However, if the planting date is delayed too long, small plants and consequently small bulbs are formed.

Usually some cultural adjustments need to be made with new cultivars; it is seldom that any two cultivars can be treated exactly alike. Several years are needed for a grower to become acquainted with the characteristics of new cultivars, to evaluate them properly, and to determine what cultural changes need to be made to produce a satisfactory crop.

IX

GROWING AND HANDLING DRY ONION SETS

In the northern United States, usually before the snow has all melted and often while the ground is still frozen, small and round, yellow, white, or red, onion sets appear in shop windows in various types of containers. They remind the gardener that planting time is not far away. Although onion sets appear in early spring as if by magic, they usually have been in storage for 6 to 8 months, and are responsible for a rather highly specialized industry. Thousands of home gardeners rely upon onion sets for the production of early green onions, and for a limited quantity of mature onions. Their use in growing the large-bulb commercial crop is described in Chapter XI.

The term 'set' as used in this chapter is applied to any small dry onion bulb, usually less than 1 in. in diameter, which is produced by sowing seed thickly to stunt the growth of the plant. In the United States, between one and two million bushels of sets are produced annually. They are usually grown as a highly localized crop, mostly near Chicago, Illinois, but some are grown under irrigation near Greeley, Colorado, and in other districts that are scattered throughout the northern States. In Canada about 400 acres are raised in the Red River Valley near Winnipeg, Manitoba, and about 125 acres in the Thedford district of Ontario. In Hungary about 2,000 tonnes are grown in the Mako district. In Yugoslavia the main districts of set production are Beograd in Serbia, Mostar in Hercegovina, and Skopje in Macedonia. Sets are also grown extensively in the Netherlands and other north European countries.

SOILS AND THEIR PREPARATION

Onion sets are grown most satisfactorily in mineral soils; muck soils tend to produce plants with heavy tops and thick necks, making curing difficult. The soil must be retentive of moisture but non-packing and friable; sandy soils may dry too rapidly in hot weather and thus reduce yields. Under irrigation the crop is usually grown on a medium-heavy soil or sandy loam. The slope of the land is important; the ideal, which allows a slow flow of water, is a drop of 1½ ft in 500 to 600 ft. Satisfactory irrigation is illustrated in (Pl. 20(*a*)). If the slope is too great, the furrows will erode, leaving the beds too high to irrigate effectively.

It is necessary to prepare as perfect a seed-bed as possible to obtain a uniform stand of seedlings. Thin stands result in over-sized bulbs which are worthless as sets. Land for sets is usually ploughed in the autumn, so that it can be worked with the disk and harrow early in the spring. It is then pulverized and smoothed, to put the surface in final shape for sowing. In the onion set district of Greeley, Colorado, land is prepared by levelling it with a float, then ploughing furrows 28 in. apart, and finally smoothing the beds or ridges. The beds are 20 in. across the top, and the furrows about 4½ in. deep. To make firm and well-shaped beds which neither crumble nor pack, the soil should be slightly moist.

GROWING THE CROP

In most districts, seed is sown as early in the spring as the seed-bed can be prepared. Near Chicago this may be in late March, but the sowing season usually extends from mid-April to early May. The planting rate is usually 60 to 80 lb. of seed per acre; sometimes it is as low as 50 lb. At Greeley, most seed is sown between April 15th and May 15th, using 80 to 100 lb. of seed per acre. These rates are twenty or thirty times those used for the production of large bulbs. Crowding stunts the plants by increasing the competition for soil moisture and nutrients, and the bulbs, which are less than an inch in diameter, mature 3 to 5 weeks earlier than the crop that is grown for large bulbs. As thick, uniform stands are necessary to obtain sets of desirable size, the viability of the seed should be known, and the rate of seeding adjusted accordingly. Where onion smut is prevalent, fungicides must be applied at planting time (Chapter XV).

In the Greeley district, seed is sown on raised beds by the use of specially built planters. These consist of two seed-drills attached to a small garden tractor. Each drill is equipped with a shoe about 6 in. wide to open the furrows. The seed falls from the hopper on to a plate near the bottom of the furrow. This plate distributes it fan-wise, in a band that is 4 to 5 in. wide and at a depth of about ¾ to 1 in. The space between rows on the bed is about 6 in. In these wide rows the seedlings are well distributed but still crowded enough to limit the size of the bulbs. In the Chicago district, three- and six-row gang seeders sow seed thickly in narrow rows that are 12 to 14 in. apart.

If, at the time the plants are emerging, a crust is formed by rains or irrigations on the surface of the soil, it should be broken as soon as possible and with a minimum of injury to the plants. Under irrigation, water is often applied at this time to prevent the formation of a crust. Tools for breaking the crust are mostly home-made—light wooden rollers covered with galvanized iron into which nails have been driven and then had their heads removed (Pl. 20(*b*)).

Plantings near Greeley get the first irrigation very soon after seeding, especially if they have been seeded in dry soil. A second or third irrigation may be given before emergence of the plants, to provide moisture while the young seedlings become established. Onions grown for sets require frequent irrigation to maintain a uniform, vigorous growth. The length of time between irrigations depends in part on the water-holding capacity of the soil; sandy or gravelly soils may require irrigation every 3 or 4 days, whereas on heavy soils, irrigation every 6 or 7 days may be sufficient.

'A high level of fertility is necessary, but too much nitrogen may be harmful. Growers learn from experience the best formula and amount of fertilizer to use. Around Greeley, side dressings of ammonium sulphate are generally applied during the growing-season. The first application is usually made about the time the plants start to bulb, and may be followed by another application if the plants seem to require it. Ammonium sulphate is generally added at the rate of 150 to 200 lb. per acre per application—usually in a narrow band about half-way up the side of the bed. This band is covered with a thin layer of soil by running a ditcher in the furrow. A small stream of irrigation water will then leach the fertilizer into the soil about the roots. Some growers make one fertilizer application, by means of a small seed-drill, in the strip of soil between the rows on the bed.

Harvesting and Curing

The harvesting of onion sets has become highly mechanized in recent years. Growers near Greeley commence harvesting while the tops are still green. The tops are cut off with a power-operated rotobeater, which consists of a rotating drum with flexible knives attached to it. The drum revolves at high speed, causing a suction that pulls the tops upright—at which time they are cut off, broken into small pieces, and spread thinly on the surface of the soil, where they do not interfere with harvesting. The sets are then dug with a modified potato digger. A blade goes under the rows and lifts the sets on to an endless belt that screens out the dirt and elevates the sets to another moving belt, which carries them to a truck at the side of the digger.

In the Greeley and Chicago districts, the sets are put in shallow trays and stacked in the field to cure for 4 to 8 weeks (Pl. 21(*a*)). The top crate is covered with roofing paper to shed rain. The standard Chicago crate is 4 in. deep, 2 ft wide, and 4 ft long. Cleats, nailed across the upper corners, serve as handles, and also provide for an air space between crates when they are stacked in tiers. These crates each hold slightly more than a bushel of sets. Greeley crates are 4 ft long and 2½ ft wide. The end walls are 6 in. high at the centre, and taper at the edges to the side-walls which are 3 in. high (Pl. 21(*b*)). A centre board divides the crate into two sections and prevents sagging in the centre. A small cleat is nailed to the inside of the end board, to facilitate handling and to provide a wider surface for stacking.

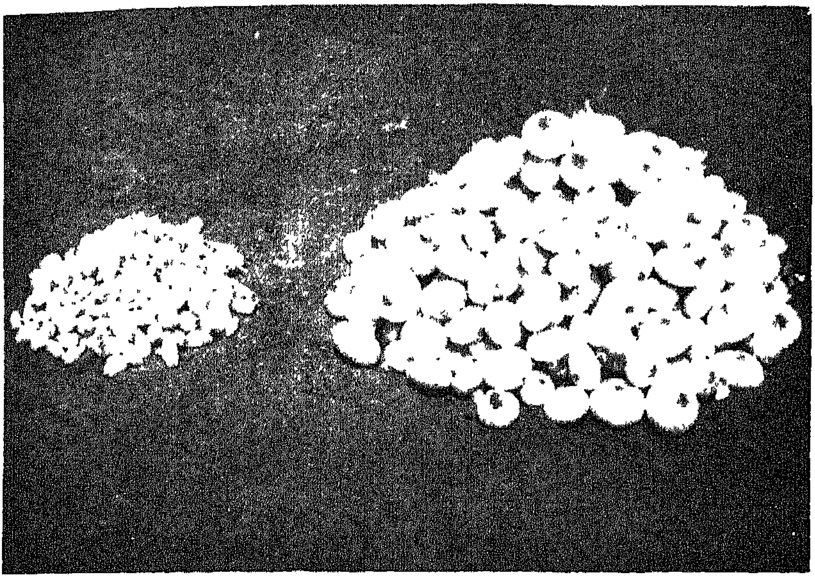


Photo U.S. Dep. Agric.

(*a*) Susceptible and resistant onion cultivars grown in pink-root-infested soil, Laredo, Texas *Right*, pink-root-resistant 'Eclipse'; *left*, a non-resistant White Grano type. These samples were grown side by side in the field

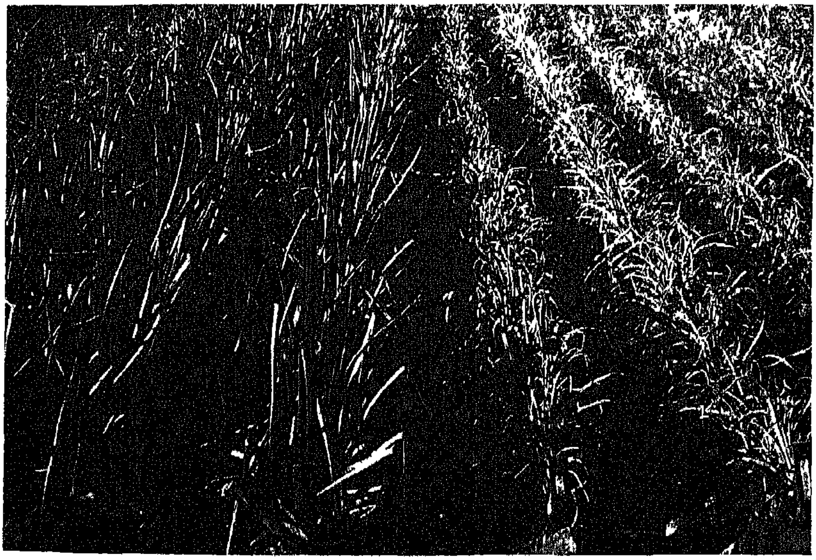
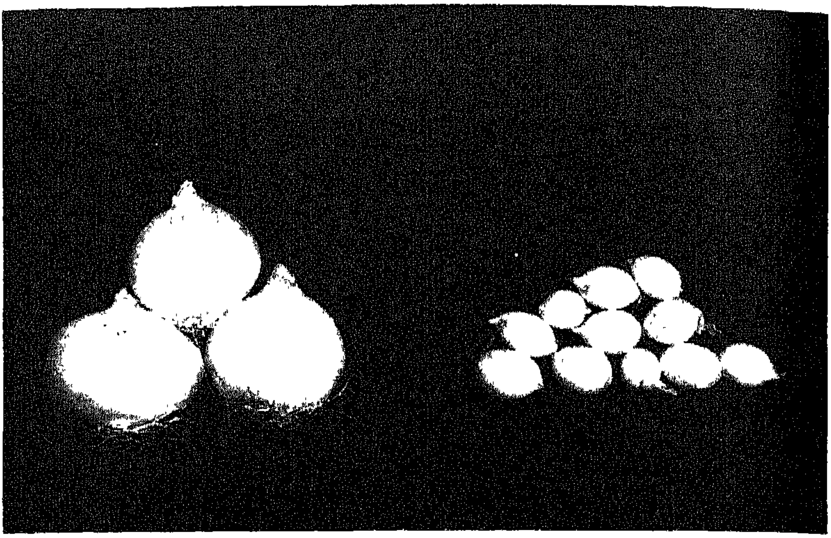


Photo Calif. Agric. Exp. Sta.

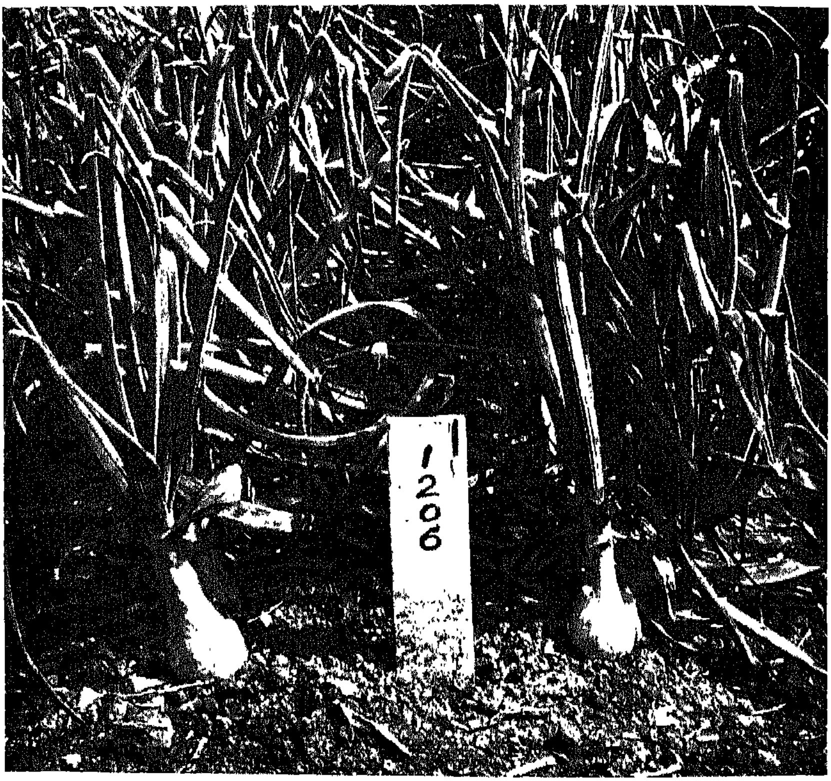
(*b*) Variation in thrips resistance of onion cultivars. *Left*, 'White Persian', highly resistant to thrips; *right*, 'Australian Brown', very susceptible and showing much injury. (H. A. Jones *et al.* 1934.) The rows are 18 in. apart.

PLATE 18



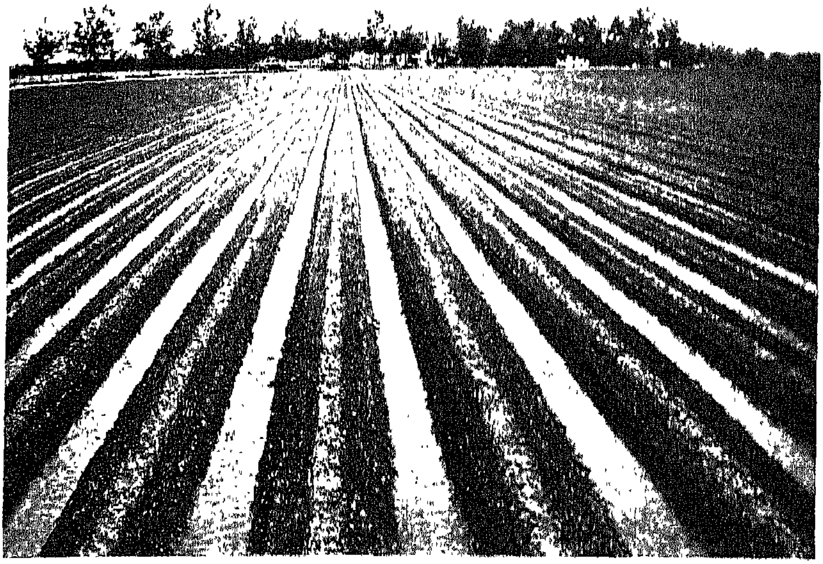
(*a*) Early 'White Grano'. *Left*, bulbs grown as a winter crop at latitude 33° N.; *right*, the same cultivar grown as a summer crop at latitude 44° N. (One-fourth natural size.)

Photos Dessert Seed Co., Inc.



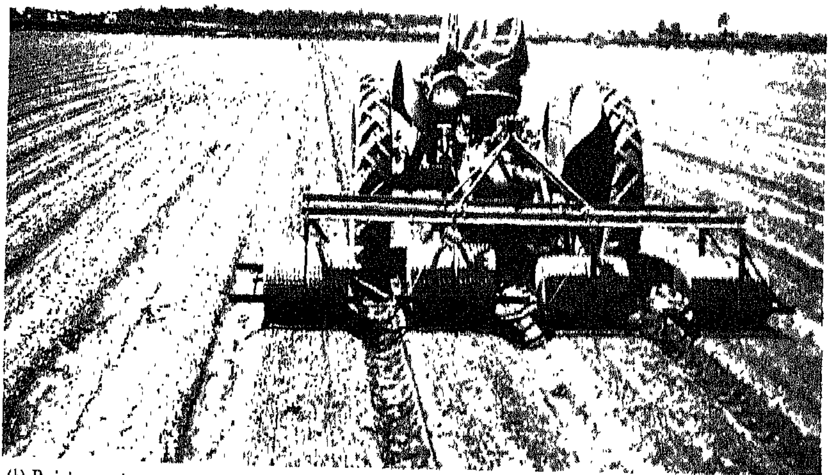
(*b*) 'Southport White Globe' grown under short-day conditions. Bulbing was initiated but the bulbs did not mature. No known cultural practices can adapt this long-day onion to short-day conditions.

PLATE 19



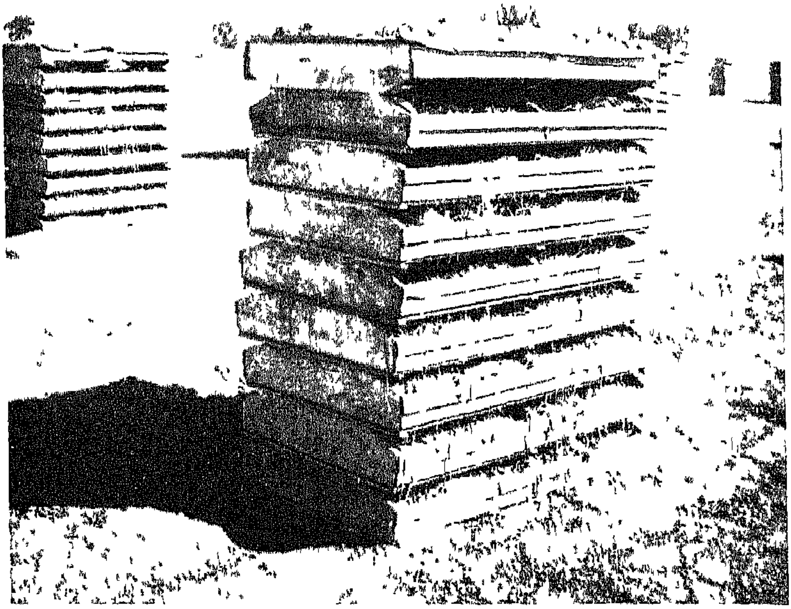
(*a*) Irrigating young onion seedlings for the production of dry sets. A slow flow of water prevents washing away of the soil; the ditches are 28 in. centre to centre. Greeley, Colorado.

Photos U.S. Dep. Agric



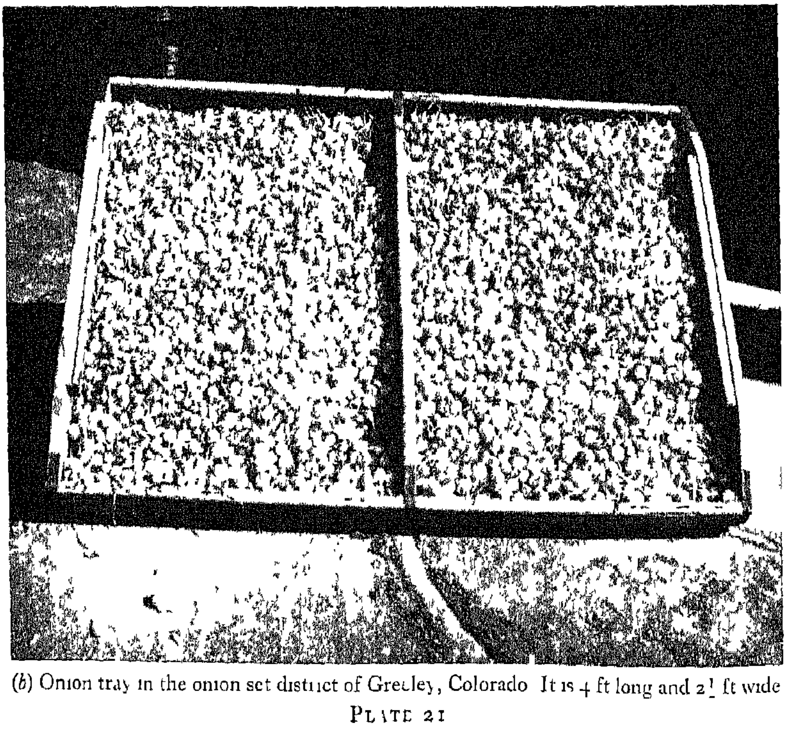
(*b*) Raising onion sets. Spiked rollers are used to break the crust over the rows, so helping the seedlings to emerge. Greeley, Colorado.

PLATE 20



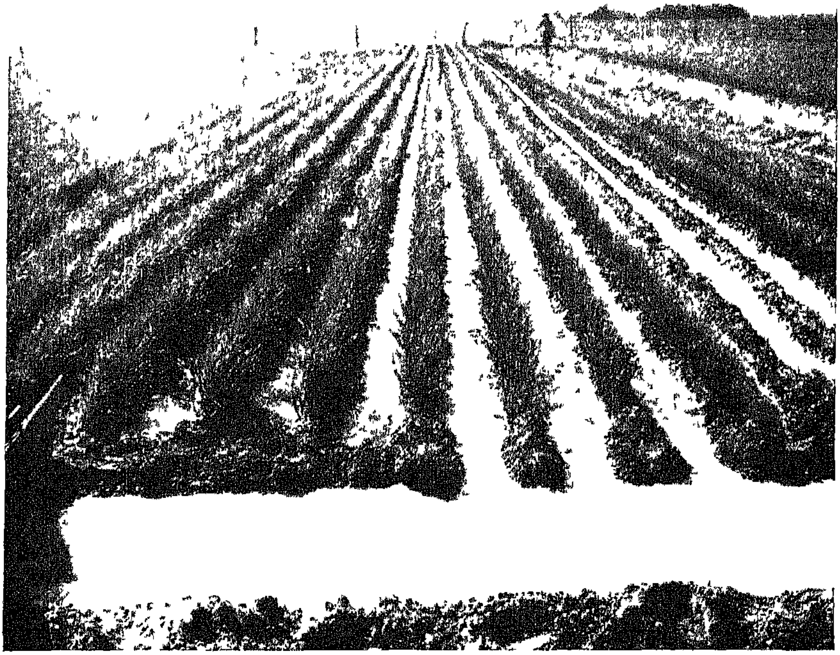
(*a*) Trays of onion sets stacked in the field to cure Each crate is 4 ft long and 2½ ft wide. Greeley, Colorado

Photos Dessert Seed Co, Inc

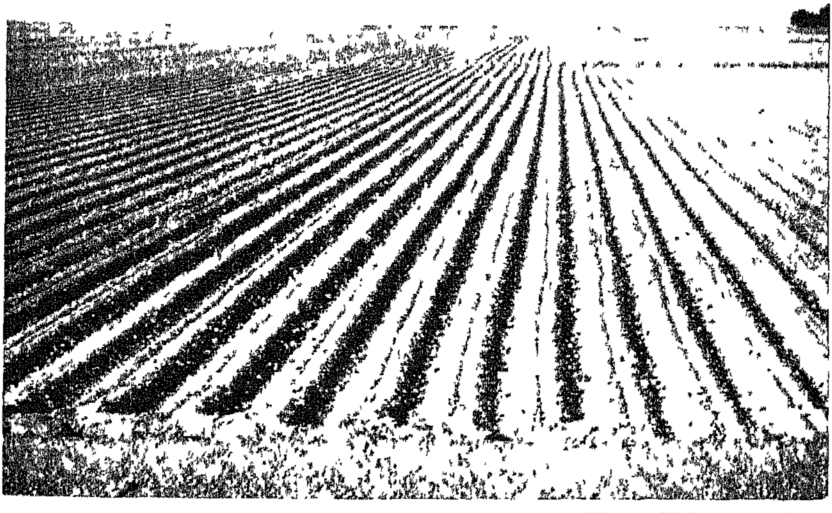


(*b*) Onion tray in the onion set district of Greeley, Colorado It is 4 ft long and 2½ ft wide

PLATE 21



(*a*) Irrigating onions which are being grown for transplanting (i.e. 'transplants'). The land should have a gentle slope so that the soil will not wash away. Crystal City, Texas



Photos U.S. Dep. Agric.

(*b*) Single rows seeded 16 in. apart in dry soil on raised beds for the growing of onion transplants. Water will be run in the furrows to germinate the seed. Crystal City, Texas

PLATE 22

Photo Calif. Agric. Exp. Sta.

(*a*) Onion transplants. Seedlings [illegible] bed. Peat soil in the Delta district of C[illegible]

(*b*) For large-scale production of on[illegible] [illegible] are used to kill weeds and to open furrows for a [illegible] Crystal City, Texas.

Photos U.S. Dep. Agric.

(*c*) Pulling and tying onion transplants for shipment. About 100 transplants are tied in a bunch, and these are allowed to dry for several hours before being packed in crates. Crystal City, Texas.

PLATE [illegible]

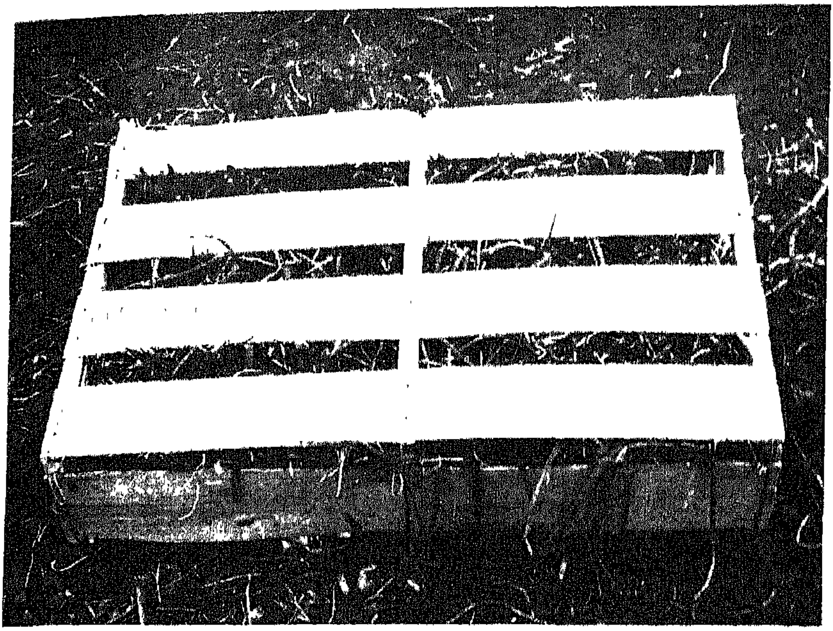


Photo U.S. Dep. Agric.

(*a*) Onion transplants packed for shipment. The bunches, with the tops trimmed, are placed upright in shallow crates. Crystal City, Texas.

Photo Dessert Seed Co., Inc.

(*b*) Growing onion transplants in sunken seed-beds, Cortazar, Mexico. The seed is broadcast and thick stands are obtained. The above land has been in onion seed-beds continuously for thirty years.

PLATE 24

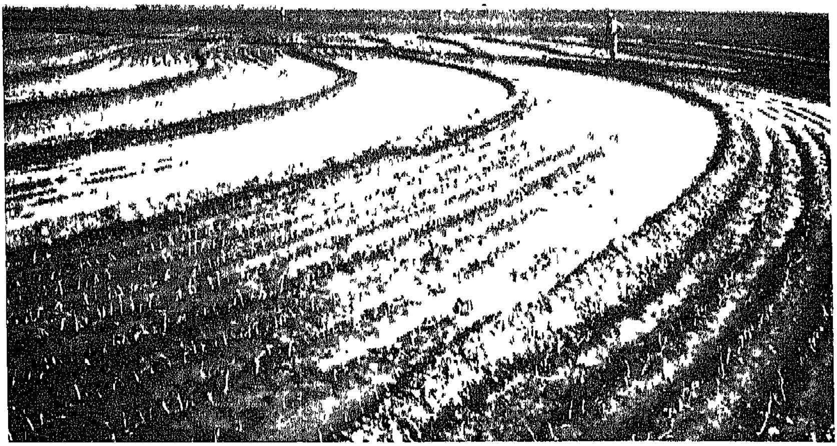


Photo U S Dep Agric

(*a*) Irrigating onions transplanted on the contour in southwestern Texas This method is adapted to land with a moderate slope Border ridges 6 to 8 in high and parallel to each other are made across the slope, at a controlled grade, and the onions are planted between the ridges, usually on low beds (H A Jones *et al* , 1957)

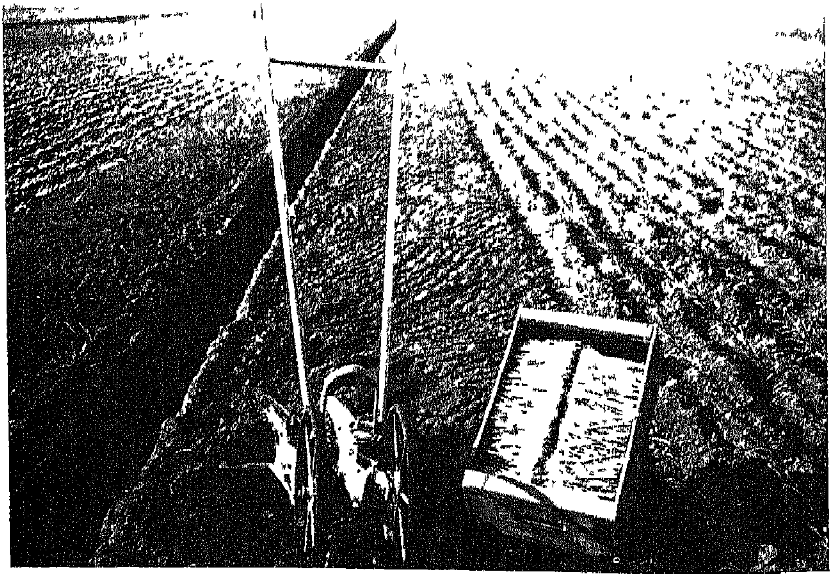


Photo California Agric. Exp Sta.

(*b*) Transplanted onion seedlings on peat land in the Delta district of California. Seedlings are laid in a slanting position against the side of the furrow The right-hand plough of the cultivator covers the last row of seedlings planted, while the left-hand plough opens a new furrow Soil from the irrigation ditch has been levelled on either side and will be planted, so that all of the land is utilized (H A Jones *et al* , 1944*a*)

PLATE 25

STORAGE

In the United States, cured onion sets are moved in crates to insulated warehouses and stored without artificial refrigeration. During fair autumn weather the doors are left open during the day, to allow the escape of moisture given off by the sets. The doors are usually closed at night and during rainy weather. As winter approaches, the temperature of the warehouse drops gradually, and when it reaches 32° to 35°F., an effort is made to maintain this temperature. Ventilation is usually provided through roof vents and, if possible, the relative humidity is kept below 90 per cent. Doors are opened during bright clear days in winter if the temperature is not too low. Forced air circulation is unnecessary if the warehouse is well built and vents are provided along the floor and in the peak of the roof. During extremely cold weather it may be necessary to provide some heat, but this is kept to a minimum. Heat may be supplied by a central system using hot water or steam, or by stoves placed in aisles between the tiers of crates.

E. Chroboczek (1959, personal correspondence,) gives some interesting observations on methods of storing sets in Hungary, Poland, and Yugoslavia. In Hungary, at the beginning of winter, the sets are heated at 35°C. for 10 to 50 days, the large sets being given the longest heat-treatment. For the remainder of the storage season the sets are held at 18°C. In the Mako district of Hungary there are several storage houses, each with a capacity of about 400 tonnes. Formerly all sets were stored in the living-room of the individual grower, and to some extent this is still done, the sets being placed about 30 cm. deep on reed mats on the rafters beneath the ceiling. Heat is supplied by burning maize stalks in a brick stove.

In Poland the small farmers grow their own sets and keep them from November until the end of January in baskets beside the kitchen stove, or in sacks placed on boards or laths over the stove. The method of storing varies with the size of set; the largest sets are placed nearest to the stove, where the temperature is about 25°C. or higher, and the smaller sets are brought in later and placed farther from the stove. The market gardeners in Poland have special rooms for drying sets. These vary in size, but are usually about 4 × 6 m., and each has heating ducts which lead to a chimney built in the brick wall. Coal is used as fuel. The sets are stored from early November to late February, usually at a temperature of 20° to 25°C.; however, some gardeners prefer keeping larger sets at 25° to 30°C. This heating and drying procedure is mainly for sets ranging from 17 to 25 mm. in diameter and is rarely used for smaller sets. The dried sets usually lose about 40 per cent of their weight and, therefore, must be sold at a higher price than non-dried sets.

In Yugoslavia, sets are not heated during storage. In Serbia they are stored in the attic under reed roofs, to protect them from freezing, or under cover of straw mats during cold winters; in Hercegovina, large storage houses are used in which the sets are placed on shelves in layers 25 cm. thick.

The temperatures to which sets are subjected in storage have a tremendous influence on seed-stalk production (bolting) in the crop that is grown from the sets. For this reason, increased attention is being given to storage temperatures. Thompson & Smith (1938) conducted experiments over a period of years at Ithaca, New York, with 'Ebenezer', 'Yellow Globe', and 'Red Wethersfield'. Sets were kept in controlled-temperature storage at 30°, 32°, 40°, and 50°F., and in common storage at 60° to 70°F. The 30°F. temperature was used only during the three years 1933–35; the other temperatures were used throughout the five-year period of 1932–36. Early in the spring, the sets were graded into three sizes according to diameter: large ($\frac{13}{16}$ to 1$\frac{1}{8}$ in.), medium ($\frac{5}{8}$ to $\frac{3}{4}$ in.), and small ($\frac{3}{8}$ to $\frac{5}{8}$ in.). The sets were planted in late April or early May, were spaced 3 in. apart in rows 18 in. apart, and later were carefully observed for bolting. For all cultivars and for all sizes, the highest percentage of bolters was from the sets that had been stored at 40° and 50°F. The least amount of bolting was from sets that had been stored at 60° to 70°F., but at this temperature there was considerable loss from wither-

TABLE X

PERCENTAGE OF BOLTERS FROM LARGE, MEDIUM, AND SMALL SETS, OF THREE CULTIVARS EACH STORED AT FIVE TEMPERATURES. THE 30°F. STORAGE WAS USED DURING THREE YEARS; OTHER STORAGE TEMPERATURES WERE USED DURING FIVE YEARS

(Thompson & Smith, 1938)

	Percentage of bolting at indicated storage temperatures					
Cultivar	30°F.	32°F.	40°F.	50°F.	60°–70°F.	Average
			Sets $\frac{13}{16}$ to 1$\frac{1}{8}$ in. diam.			
Ebenezer	2·20	9·14	40·98	35·02	1·58	19·77
Yellow Globe	33·37	42·70	79·98	68·64	18·51	52·27
Red Wethersfield	40·36	68·10	84·38	78·86	24·58	66·00
Average	24·66	37·70	67·37	59·41	13·17	43·63
			Sets $\frac{5}{8}$ to $\frac{3}{4}$ in. diam.			
Ebenezer	0·18	0·34	2·05	1·33	0·08	0·88
Yellow Globe	4·69	4·88	21·58	14·07	2·70	10·54
Red Wethersfield	8·25	9·72	26·60	20·56	6·25	15·44
Average	4·15	4·53	15·78	10·90	2·45	8·21
			Sets $\frac{3}{8}$ to $\frac{5}{8}$ in. diam.			
Ebenezer	0·00	0·00	0·00	0·06	0·08	0·03
Yellow Globe	0·11	0·00	1·28	0·88	0·08	0·54
Red Wethersfield	0·10	0·37	1·13	0·30	0·29	0·47
Average	0·07	0·11	0·78	0·42	0·14	0·33

ing. Of the temperatures used, 30°F. appeared to be the most practical, and 32°F. the next-best. Bolting was highest in large sets, and lowest in small sets, at all temperatures (Table X).

A number of investigators have shown that bolting can be reduced by storing sets at temperatures somewhat higher than those used by Thompson & Smith. Beekom (1952), working in the Netherlands with a Rijnsburger-type onion, stored sets of three sizes at 25·5° to 28°C. In the spring the sets were planted in the field, and the number of bolters and the yield of marketable bulbs were determined. In one experiment the sets were stored on October 1st and samples removed to common storage at intervals from January 15th to April 1st. This was done to determine whether sets that have been placed at a high temperature early on need be kept at this high temperature, or whether they can be removed to common storage before April 1st. The data in Table XI show that, even when high-temperature treatment is started on October 1st, it should be continued to April 1st to obtain the greatest reduction in bolting and the highest yields. This is especially true for medium- and large-sized sets.

TABLE XI

INFLUENCE OF DURATION OF WARM STORAGE (25·5° TO 28°C.) ON BOLTING AND YIELD OF BULBS FROM THREE SIZES OF SETS OF RIJNSBURGER-TYPE ONION. AVERAGE OF TWO YEARS' RESULTS

(Beekom, 1952)

Period of storage at 25·5° to 28°C.	Set diameter 10–15 mm.		Set diameter 16–20 mm.		Set diameter 21–26 mm.	
	Yield (kg/are)[1]	Bolters (%)	Yield (kg/are)	Bolters (%)	Yield (kg/are)	Bolters (%)
Oct. 1st–Jan. 15th	564·1	7·9	325·1	45·9	156·9	71·3
Oct. 1st–Feb. 1st	556·5	6·6	437·0	34·8	207·8	67·2
Oct. 1st–Feb. 15th	584·9	5·8	500·4	26·6	362·0	51·0
Oct. 1st–Mar. 1st	619·8	3·8	580·9	19·8	480·3	37·8
Oct. 1st–Mar. 15th	621·3	3·5	648·9	13·2	562·7	29·2
Oct. 1st–Apr. 1st	625·3	2·4	670·7	8·5	620·7	20·3

[1] 1 are = 100 sq. m.

In another experiment, Beekom placed one lot of sets at high temperature on October 1st, and then delayed treating other lots—to determine whether a shorter exposure would have the same beneficial effect in reducing the number of bolters and increasing yield. He found that, as the heat-treatment was shortened through beginning later and later (from October 1st to December 1st), there was a gradual increase in bolting and reduction in yield (Table XII). Any shortening of the heat-treatment, whether at the beginning or at the end of the storage season, gave an increase in bolting and a decrease in yield, and these responses were greatest with the largest sets. If it is impossible to give the warm treatment for the full period from October 1st to April 1st, it is better to start the treatment a little late than to finish too early. Thus a warm treatment during the last weeks before April 1st is of more importance than during the first few weeks following October 1st, and after warm-temperature storage the sets should be planted as soon as possible. As a result of this work, storage of sets at high temperatures has become a commercial practice in the Netherlands, where, already in 1950, there were twenty-three storage houses that had facilities for high-temperature treatment. These special storage houses had a total capacity of 1,250 tonnes of sets.

TABLE XII

INFLUENCE OF TIME OF STARTING WARM STORAGE (25·5°–28°C.) ON BOLTING AND YIELD OF BULBS FROM THREE SIZES OF SETS OF RIJNSBURGER-TYPE ONION. AVERAGE OF TWO YEARS' RESULTS

(Beekom, 1952)

Period of treatment	Set diameter 10–15 mm.		Set diameter 16–20 mm.		Set diameter 21–26 mm.	
	Yield (kg/are)[1]	Bolters (%)	Yield (kg/are)	Bolters (%)	Yield (kg/are)	Bolters (%)
Oct. 1st–Apr. 1st	625·0	4·1	659·6	12·8	571·3	27·4
Oct. 15th–Apr. 1st	613·4	3·3	662·5	13·1	561·3	28·2
Nov. 1st–Apr. 1st	619·6	2·9	634·2	15·5	533·4	32·6
Nov. 15th–Apr. 1st	610·9	4·4	594·2	19·5	434·2	42·4
Dec. 1st–Apr. 1st	567·5	7·4	500·0	29·4	314·2	54·8

[1] 1 are = 100 sq. m.

Heath (1943), in England, found that when 'Ailsa Craig' sets were stored at 30°C. throughout the winter (22 weeks), bolting was practically eliminated. Storage of the sets for 8 weeks at 30°C., followed by 14 weeks of common storage (mean 12·5°C.), reduced bolting, but 14 weeks of common storage (mean 12·1°C.) followed by 8 weeks at 30°C. was much less effective. Cold storage (0°C. to 1·5°C.) continuously, or for 8 weeks followed by 14 weeks of common storage, reduced bolting considerably.

Lachman & Upham (1954), in Massachusetts, selected sets from common storage that were 1¼ in. in diameter and moved them in February to storage at 86° and 32°F. Three lots were held at 86°F. for 9, 7, and 5 weeks. After planting on April 24th, they bolted 11·4, 17·5, and 38·5 per cent, respectively; after planting on May 15th, 0·2, 1·6, and 0·9 per cent bolted. A lot stored at 32°F. for 9 weeks and planted on May 15th bolted 81·5 per cent. Late planting considerably reduced the bolting of the high-temperature treatments, but had little effect on the sets stored at low temperatures. In another experiment, sets 1, ¾, and ½ in. in diameter, were stored for 9 weeks at 86°F., and similar lots were stored at 32°F. The large, medium, and small sets stored at 86°F. bolted 6·3, 0·1, and 0·0 per cent; those stored at 32°F. bolted 43·1, 2·1, and 0·0 per cent, respectively.

The objective of all of the above storage investigations, and of others which have not been reported here in detail (e.g. Mánczak, 1959; Lachman & Michelson, 1960), was to find, for sets, temperatures and storage periods which would inhibit bolting in the subsequent crop. The data show quite conclusively that storage at both high (above about 80°F.) and low (32°F. or below) temperatures results in less bolting than storage at intermediate temperatures—especially those around 45° to 55°F. Plants developing from sets that are less than ½ in. in diameter rarely bolt, regardless of storage temperature. For the larger sets, high storage temperatures seem to be somewhat more effective than low temperatures in suppressing bolting. Because all cultivars do not react alike to storage conditions, the best temperature and storage-period combinations must be determined for each cultivar.

HANDLING AND GRADING AFTER STORAGE

In the United States, sets are usually processed and graded during late winter and early spring, before being distributed. They are often fanned to blow out light sets, loose scales, and dust, then run over an endless belt where sprouted and rotted sets are removed by hand, and are finally graded for size.

The U.S. Department of Agriculture has instituted certain standards for the onion-set trade—to provide the remote buyer with a true picture of the sets within a grade, and to serve as a basis for the settlement of disputes. For example, onion sets sold as *U.S. No. 1* shall be of similar varietal characteristics and shall be mature, fairly firm, free from decay and from damage caused by tops, sprouting, freezing, mould, moisture, dirt, chaff or other foreign matter, disease, insects, or mechanical or other means. The minimum diameter is $\frac{5}{16}$ in. and the maximum diameter is 1 in., but at least 40 per cent by weight of the sets must be between $\frac{5}{16}$ and ¾ in. in diameter. Sizes below 1 in. may be specified for this grade as *U.S. No. 1, ¾ inch maximum*, but sizes must be stated truthfully. Apart from size, a total of 6 per cent by weight of the sets in any lot may be below the requirements of the grade; not more than 2 per cent is allowed for decay, and not more than 2 per cent for dirt, chaff, or other foreign matter. In addition, 8 per cent by weight may be larger than the specified maximum size, and not more than 3 per cent by weight may be below the specified minimum size.

Detailed specifications for the different U.S. grades of onion sets can be obtained from the Agricultural Marketing Service, United States Department of Agriculture, Washington, D.C.

X

GROWING AND HANDLING TRANSPLANTS

In the United States, between one-quarter and one-third of the onion bulb crop is raised from transplants. In Egypt almost the entire crop is transplanted. In Italy, Spain, India, Iraq, and many other countries, the transplanting method is used extensively. As such a large part of the crop is grown from transplants, it is obvious that the production of the transplants themselves constitutes a substantial industry. The commercial production of large bulbs from transplants is most prevalent in regions where the onion crop is grown during the winter and harvested in the spring, but it is also practised where onions are grown as a summer crop—not only to give a longer growing-season for late-maturing cultivars, but also to give early-maturing types an opportunity to make considerable growth before long days and high temperatures force them to bulb.

GROWING TRANSPLANTS IN THE OPEN

For the winter crop in warm climates, most transplants are grown in the autumn in open seed-beds or nurseries. In the southern United States, especially in southern Texas, it is not uncommon for individual farmers to grow 5 to 10 acres of transplants for their own use—or 100 acres or more if they are growing transplants for sale.

Friable soil that is free from trash and diseases should be chosen for seeding. Pink-root is prevalent in many districts of the southern United States. When onions are planted on the same land year after year, the population of pink-root fungus builds up in the soil and becomes widely disseminated at transplanting time. Growers should avoid using land on which onions have been grown during the preceding 4 or 5 years.

Where rainfall is adequate and the land well drained, seed may be planted on the level in rows 12 to 18 in. apart. In districts of excessive rainfall, seedlings are grown on raised beds to provide drainage. Where surface irrigation is used, it is necessary to plant either on raised or sunken beds. Several methods of applying water are used, depending upon the contour of the land and the texture of the soil. In the southwestern United States, most of the seedlings are grown on raised beds. These may be low, narrow beds 14 to 16 in. from centre to centre, with one row to the bed (Pl. 22(*b*)), or slightly wider beds, with two or more rows to a bed (Pl. 23(*a*)). Irrigation water is applied in the furrow (Pl. 22(*a*)).

On gently sloping hill-sides, raised beds with furrows between them for irrigation are often made across the slope, the grade being carefully selected to reduce the danger of erosion. Often, raised borders 10 to 12 ft apart are made on the contour of the land. The land is levelled between the borders, and the seed is drilled on low beds, which are furrow-irrigated. If desirable, cross borders can be made to form small sunken beds or basins that can be flood-irrigated after the seed has been drilled in or broadcast. Such beds have been used in some areas of Mexico for many years (Pl. 24(*b*)). In Egypt, sunken beds from 10 to 12 square metres in size are used. Seed is broadcast in these at the rate of 70 to 100 lb. per acre, covered lightly with soil, and the beds are flooded. A similar practice is followed in the Valencia district of Spain. On the peat lands of central California, rows are planted close together on wide beds (Pl. 23(*a*)). These are irrigated by raising the water-table nearly to the surface. In most irrigated districts, seed is planted in dry soil and water is added later.

In producing transplants, the object is to get as many healthy, hardy plants of the desired size from as small a seed-bed area as possible. About 112,000 transplants are required to set an acre of commercial onions spaced 4 in. apart in the row, with 14 in. between rows. This number of transplants can be grown on about one-tenth of an acre of land that has been sown with 2 lb. of seed; e.g. one acre of seed-bed, when planted with 17 to 20 lb. of seed, will produce enough transplants to set 10 acres. Seeding that is too thick produces spindly plants, so that the rate of seeding should be carefully controlled. Some growers use a spreader on the planter to scatter the seed over 2- to 4-in. strips. In these wide rows, seeding rates can be higher; but if the land is weedy, such rows may require more hand-labour than other types.

Seedlings must be hardy to withstand the rigours of transplanting. Often they are set in dry soil and are not irrigated for 3 or 4 days. A well-conditioned plant that has been hardened by withholding water for 10 to 14 days will survive this treatment and start growth as soon as water is added.

Cultivation of the growing crop is chiefly for the purpose of killing weeds, and should always be shallow. In many countries where labour is plentiful and cheap, the hand hoe is the chief implement of tillage; but in others, tillage is highly mechanized. Tractors with all sorts of attachments are used to destroy the weeds, break the crust that is formed after irrigation, and open the furrow for the next irrigation (Pl. 23(*b*)).

At transplanting time the seedlings may be given an irrigation, loosened with a spade or fork, or undercut with a tractor-drawn blade, to facilitate pulling. Workers usually accumulate a handful of plants, shake the soil from the roots, and cut off a portion of the tops with a knife or twist them off by hand. If the roots are long, they are trimmed with a knife or shears, whole bunches being trimmed at one time. The pruned seedlings are about 5 to 6 in. long. Pruning facilitates planting, and although tests have shown that pruning reduces yields, many large growers feel that the ease of resetting pruned plants more than compensates for the reduction in yield. The amount of pruning of transplants may vary considerably, and the transplant grower can also vary the size of the transplants through his control of time of planting, of irrigation, and of fertilizer level. Both pruning and the size of the transplants may have a marked effect on the crop which is grown from transplants. Several workers have investigated these effects.

A 5-year test in Texas (Hawthorn, 1938), comparing unpruned plants of 'Yellow Bermuda' with plants that had both tops and roots pruned at the time of setting, showed that pruning significantly reduced yields (Table XIII). These data also show that pruning either tops or roots is not as injurious as pruning both.

TABLE XIII

EFFECT OF PRUNING ONION TRANSPLANTS ON YIELD OF MATURE BULBS

(Hawthorn, 1938)

			Year			
Treatment	1933	1934	1935	1936	1937	Average
			Yield in bushels per acre			
Tops and roots pruned	301	298	164	317	484	318
Tops pruned	254	370	221	321	508	335
Roots pruned	343	270	200	361	497	334
No pruning	399	316	178	350	528	354

Experiments conducted in California (G. N. Davis & Jones, 1944) give further evidence of the detrimental effect of pruning (Table XIV). Five varieties had their roots cut to a length of 1 in. and their tops cut to a length of 5 to 6 in. above the stem plate. A considerable reduction in yield occurred when both tops and roots were pruned, but the reduction was not always statistically significant. Root pruning seemed to be less damaging than top pruning, but neither was as detrimental as pruning both the tops and the roots. On large acreages, where rapid planting is necessary, no doubt the practice of pruning will be continued; but in small plantings, especially where high returns are essential, the value of this practice seems questionable.

The size of transplants is important, but grading for size is too costly for large operators who handle millions of plants. For this reason, it is important that the seedlings in the field be uniform in size, and also that

TABLE XIV

EFFECT OF PRUNING ONION TRANSPLANTS ON YIELD OF MATURE BULBS

(G. N. Davis & Jones, 1944)

Treatment	California Early Red 1930	Stockton Yellow Globe 1931	Red 21 1934	San Joaquin 1942	Crystal Grano 1942
	Cultivar and Year				
	Yield in 100 lb. bags per acre				
Tops and roots pruned	478	367	307	262	105
Tops pruned	527	412	314	273	127
Roots pruned	534	428	314	273	151
No pruning	589	427	361	320	147
Least Significant Difference at 5%	33	56	31	N.S.[1]	N.S.[1]

[1] Not significant

they reach a desired size on a specified pulling date. This requires uniform seeding, proper fertilizing, irrigation, and weed control, and also a knowledge of the cultivar. Certain cultivars grow faster than others and should be planted later. For example, hybrid Granex makes very rapid growth, and, if it is planted early, too large a seedling will be over-wintered and the plants will bolt instead of bulbing.

Oversize plants are often the result of poor stands in the seed bed. In California, G. N. Davis & Jones (1944) showed the effect of size of transplant on bolting in over-wintered 'Grano'. The transplants were graded into eight sizes according to their diameter at the base of the plant. Some swelling occurred during the autumn, which accounts for the extra-large sizes (Table XV). With transplants of 'Grano' below ¼ in. there was very little bolting; with the larger sizes the percentage of bolting increased rapidly, and above ¾ in. practically all of the plants bolted. For all sizes above ¼ in., bolting was sufficiently high to make commercial production unprofitable.

TABLE XV

INFLUENCE OF TRANSPLANT SIZE ON BOLTING IN THE 'GRANO' ONION, LIBERTY ISLAND, CALIFORNIA

(G. N. Davis & Jones, 1944)

Seedling diameter (in.)	Bolters (%)	Seedling diameter (in.)	Bolters (%)
Under ⅛	0·0	½–⅝	85·2
⅛–¼	1·4	⅝–¾	88·4
¼–⅜	36·0	¾–⅞	97·2
⅜–½	73·4	⅞–1	100·0

The size of a plant that can be over-wintered without bolting depends partly upon the cultivar. Highly non-bolting types, such as California Early Red, are used for the transplant crop in central California. Four strains of this cultivar were used to determine the effect of transplant size on yield (G. N. Davis & Jones, 1944). The transplants, which were compared each year, were of the same age but of two sizes (Table XVI). The bulbs from the large seedlings out-yielded those from the small seedlings, over the four successive years, by 38, 38, 25, and 26 per cent, respectively. These data show the distinct advantage of large transplants so long as bolting is not a problem.

TABLE XVI

EFFECT OF LARGE AND SMALL ONION TRANSPLANTS ON YIELD OF MATURE BULBS, DAVIS, CALIFORNIA

(G. N. Davis & Jones, 1944)

Year	Cultivar	Size of transplant	Weight of trimmed transplant (gm.)	Yield per acre (100-lb. bags)
1927	Red 21	Small	1·08	312
		Large	2·19[1]	430[1]
1928	California Early Red 21–9	Small	1·06	262
		Large	2·56[1]	361[1]
1929	California Early Red	Small	1·86	507
		Large	3·88[1]	635[1]
1930	California Early Red 21–24	Small	2·60	354
		Large	5·38[1]	479[1]

[1] Difference significant at the 1 per cent level.

GROWING TRANSPLANTS UNDER COVER

For early spring planting in cold climates, seed is usually planted in cold-frames, greenhouses, or hotbeds, 10 to 12 weeks before the plants are to be set in the field. The seed is commonly sown thinly, 10 to 12 seeds to the inch, about ½ in. deep in rows about 4 in. apart. Because of susceptibility to damping-off, seedlings are much more difficult to grow indoors than in the open. Dusting seed with a disinfectant, used as recommended by the manufacturer, usually helps. Care must be used in watering, especially while the plants are small. On cloudy days, watering should be avoided, and on bright days it should be done only in the early morning, so that the soil surface will dry before night. After the first true leaf has appeared, there is much less danger of damping-off than at earlier stages.

The best seedlings are produced at cool temperatures. A night temperature of 50°F. and a day temperature of 60° to 65°F. are satisfactory, but slightly higher temperatures will do no harm on clear days.

Plants that have been grown indoors should be set in the field as soon as freezing weather is over. If the seedlings are tender, they should be hardened somewhat by withholding water and exposing to night temperatures that are only slightly above freezing for a week or ten days before they are planted in the open.

In some of the eastern counties of England, growers plant onion seed in glasshouses or cold-frames in January or early February—for transplanting on open land, usually during April. In the northern United States nowadays, transplants are not grown under cover in such quantity as they were formerly, but are shipped in from the South.

GROWING AND HANDLING TRANSPLANTS FOR SHIPMENT

The production of transplants for shipment is an industry of major importance in the southern United States. Shipped over a period of several months, transplants go first to near-by markets, then to markets situated farther and farther north as the season advances, until ultimately they reach those in the most northern parts of the United States and southern Canada. Most plants are used by home gardeners who like to produce a mild table onion, but some are used by commercial growers to get an early crop.

The chief problem of the transplant grower is to estimate and meet the demand for plants when they will be needed. He must know the approximate time required to grow a transplant as the season changes. Growth can be speeded up or retarded by the regulation of irrigation. Certain cultivars, especially F_1 hybrids, develop rapidly, and require less time to reach transplanting size than do most standard varieties.

Seedlings are usually pulled and tied in bundles of about 100 plants (Pl. 23(*c*)). These are allowed to lie in the open for several hours to evaporate excess moisture. The roots and tops are trimmed and the bundles of plants are packed upright for shipment in dry, well-ventilated flat crates (Pl. 24(*a*)).

XI

GROWING THE CROP

LARGE mature bulbs are produced by planting in the field either seed, dry sets, or transplants. Each of these methods is used extensively, but in certain countries one method may predominate. In Canada, for instance, most of the crop is direct-seeded, while in Mexico, Egypt, Spain, and Italy, mature bulbs are produced chiefly from transplants. In Bulgaria and Iraq, production is primarily from sets. In the United States, all three methods are used extensively: the winter crop in the southern States is largely from transplants, the northern summer crop for storage is direct-seeded, and the one for immediate sale is usually grown from dry sets. In the Netherlands, direct seeding predominates, but sets are also used. In Poland most onions are direct-seeded, but in the Warsaw district bulbs are produced from both transplants and sets. Factors such as cultivar, season of growth, time of maturity, available labour, cost of production, etc., determine which of the above methods is to be practised. Green onions are produced chiefly by direct seeding and from sets.

GROWING LARGE ONIONS FROM TRANSPLANTS

In most countries some onions are grown from transplants either in the home garden or for the commercial crop. Transplanting is more general in warm climates where onions are grown during the winter, but it is also practised where onions are grown during the summer. By setting transplants in the open as soon as spring weather permits, short-day cultivars are enabled to make considerable growth before long days force them to bulb; those cultivars that require a long growing-season will often mature when transplanted, but not when direct-seeded. Because of the equal spacing, transplants usually produce attractive bulbs of uniform size and shape. As transplants are placed deeper in the soil than is seed, the bulbs produced by transplants have a greater vertical diameter. The cost of growing the transplant crop is usually higher than that of the direct-seeded crop—because of the labour involved in transplanting.

LAND PREPARATION

Where the transplant crop is grown under irrigation, soil preparation depends a great deal on the method of irrigation used. As a rule the land is ploughed, disked, harrowed, and floated. If weeds are a problem, it may be advisable to irrigate 2 to 3 weeks before planting and then to disk and harrow the ground to kill the young weeds that spring up following irrigation. The soil should be well pulverized, because clods interfere with planting. Under furrow irrigation, transplants are set on raised beds similar to those which are used for growing lettuce and carrots. These beds are 30 to 42 in. from centre to centre, and about 6 in. high. For small plantings the beds are usually made with a lister and then shaped with a sled; but for large-scale production, both operations are usually performed at one time. Two rows are usually planted on a bed. In some districts transplants are set, one row to the ridge, on low ridges from 14 to 20 in. apart. Beds or ridges can be marked for uniform plant spacing by pulling over them a light-weight metal or wooden roller with properly-spaced slats or cleats on its surface. A number of rows can be marked in one operation. On moderately sloping hill-sides, the border system of irrigation is usually practised. Ridges 6 to 8 in. high and 150 to 300 ft long are made from 5 to 12 ft apart. These are laid out on the contour of the land, so that the entire area between the ridges can be flooded (Pl. 25(*a*)). The plants are set, between the ridges, on the level or on low beds.

On the peat lands of the Delta district of California, sub-irrigation is practised. After the land is fitted, small irrigation or spud ditches are made through the field at intervals of 80 to 100 ft. These are usually 10 in. wide and 18 to 20 in. deep. The soil from the ditches is levelled, so that the land can be planted to the edge of the ditch (Pl. 25(*b*)). Plants are set on the level.

In Middle and Upper Egypt, the crop is planted on land that has been flooded by the Nile. After the water recedes, the land is ploughed by oxen or tractor, and then pulverized by hand to incorporate the new soil that has been deposited by the river (Pl. 26(*a*)). These onion plants do not receive further irrigation, so are not set on ridges (Pl. 26(*b*)).

In regions of adequate rainfall, or where overhead irrigation is practised, onion plants are usually not set on ridges; but in districts of heavy rainfall, such as those of southern Louisiana, the crop is grown on beds which have furrows between them, to provide drainage.

TRANSPLANTING

Healthy, vigorous seedlings about $\frac{1}{4}$ to $\frac{5}{16}$ in. in 'stem' diameter, and 7 to 10 in. high, are best for transplanting. While large plants produce higher total yields than either small or medium-sized ones (Chapter X), the marketable yields from very large plants may be reduced because of splits, doubles, and bolters—all 'cull' grades. Very small plants should be discarded. In a climate such as that of central California, transplants are usually set in late autumn and, as a rule, very little growth is made above ground during the winter; however, a good root system is developed, so that, with the advent of warm weather in early spring, growth is rapid.

When transplants reach the proper size, they should be transplanted and not held in the nursery. To aid in pulling, plants can be undercut or given a quick irrigation; but often they can be pulled without preliminary treatment. To facilitate transplanting, the roots, if long, are trimmed with shears or a knife, and the excess tops are cut or twisted off, so that the pruned seedlings are about 5 or 6 in. long (Pl. 27(*a*)). In most places transplanting is still done by hand. Seedlings are usually distributed just ahead of the planter. A short stick or dibble is used to make a hole for the seedling and to firm the soil after planting. Experienced planters can scatter and set as much as one-third of an acre in a day (37,000 plants), but the average performance is considerably less. On raised beds, a small furrow can be ploughed away from each side at the top, and the seedlings laid against the side of the furrow in a slanting position pointing towards the centre of the bed. The plants are set so that the rows will be uniformly 8 to 10 in. apart, to facilitate cultivation. The roots are then covered with a lister or cultivator, and water is run between the beds to settle the soil about the roots.

On the peat soils of the California Delta, a hand cultivator with two ploughs attached to it is used for planting (Pl. 25(*b*)). The right-hand plough covers the plants that have just been set, while the left-hand plough opens the furrow for the next row. The seedlings are laid against the side of the furrow in a slanting position, but gradually grow erect and do not interfere with tillage.

In Upper and Middle Egypt, transplants are set as soon as the land

TABLE XVII

SPACING IN THE ROW AND YIELD. THREE LOCATIONS IN CALIFORNIA

(G. N. Davis & Jones, 1944)

Year	Location	Cultivar	Spacing in inches						L.S.D.[1] at 5% level
			2	3	4	6	8	12	
			100-lb. bags per acre						
1927	Davis	California Early Red	—	456	409	358	309	218	45
1928	"	" " "	—	429	416	376	357	280	48
1929	"	" " "	—	738	686	573	529	380	102
1930	"	" " "	—	528	485	465	449	—	—[2]
1931	"	" " "	—	515	447	404	366	278	51
1935	Liberty Island	Early Grano	195	246	176	172	102	—	78
1935	"	Stockton G 36	676	588	488	394	286	—	82
1935	"	California Early Red	526	502	448	332	256	—	33
1942	Shafter	San Joaquin	175	162	138	107	—	—	41
1942	Davis	Crystal Grano	374	346	299	213	—	—	162

[1] Least significant difference.

[2] No significant difference.

can be fitted after the waters of the Nile recede. Plants are spaced 3 to 4 in. apart in rows which are 6 to 8 in. apart, and the roots are covered when the next furrow is made (Pl. 26(*b*)). In the Delta region of Egypt, the summer crop of onions is interplanted in the same row with cotton. Hills of cotton, with two plants in each hill, are spaced 8 to 10 in. apart, and a single onion plant is set midway between the hills. The onion transplants are set in March, at the time the cotton is seeded.

In most countries the transplants, regardless of cultivar, are spaced 3 to 4 in. apart in the row. If the spacing is closer than this, the large onion bulbs usually become misshapen and unattractive unless they are in a very loose soil. Studies of the effect on yield of spacings in the row, were made in California by G. N. Davis & Jones (Table XVII).

These data show that, for each increase in spacing, there was almost always a decrease in yield per acre, but the decreases were not always statistically significant. For the cultivars used, the best spacings were 3 and 4 in. Because of crowding, the 2-in. spacing produced misshapen bulbs. Bulb size increased with each increase in spacing, but the gain was insufficient to compensate for the decrease in the number of bulbs. As the bulbs increased in size at the wider spacings, the necks of the plants became thicker and maturity was delayed.

GROWING LARGE ONIONS FROM DRY SETS

For the home gardener, the growing of mature onions from dry sets is a much surer means of obtaining a crop than is direct seeding, and in the United States most of the onion sets produced are used in this way. In high altitudes and high latitudes, where the growing-season is short, onions can be matured from sets when it is impossible to mature a direct-seeded crop. Where the growing-season is longer, sets are often planted at the same time as the direct-seeded crop, to get early onions for market. As bulbs from sets usually mature about 3 to 4 weeks earlier than those from seed, planting sets often gives a decided price advantage.

Because of uniform spacing, bulbs from sets are usually fairly uniform in shape and size, but a disadvantage of using sets, compared with direct seeding, is their high cost. The cost of the necessary labour may also be a considerable item if sets are planted by hand. There is, moreover, the ever-present danger of distributing pests (such as nematodes) and diseases (such as smut) to non-infested land. Onion sets should not be planted adjacent to direct-seeded fields, as they provide a source of thrips for an early infestation.

LAND PREPARATION

As onions from sets are usually grown to produce a very early crop, it is essential to plant as early in the spring as possible. Autumn ploughing is thus desirable, and the growing of winter cover-crops may not be possible. The land is first worked to a fine tilth, then fertilizer is usually spread broadcast and worked into the soil before the sets are planted.

PLANTING

Formerly most onion sets were planted by hand in shallow furrows, but machines have now been developed that make the furrows, drop the sets, and cover them in one operation. For machine planting, onion sets must be graded to a uniform size. Yields from machine-planted sets are usually somewhat lower than those obtained from hand-planted sets, and according to Colby *et al.* (1945) this is because the machines do not space the sets uniformly in the row or set them in an upright position. These authors cite an experiment in which sets, planted horizontally, yielded only 75 per cent as much as those which were planted upright and, when completely inverted, yielded only 20 per cent as much. Despite reduced yields, machine planting has its advantages. A two-row power machine can plant five acres in a day; by hand this would require about 50 men. As earliness is usually important, power machinery enables the grower to plant without delay during a period of favourable weather.

Sets are usually spaced 2·5 to 3·5 in. apart in rows 12 to 16 in. apart. The distance between rows is usually determined by tillage methods; the wider spacings are usually needed for power-operated machines. In heavy soils the sets are just covered, but in light soils they are planted somewhat deeper. The quantity of sets required to plant an acre is determined by the size of set, the distance between rows, and the spacing in the row. Colby *et al.* have calulated the volume of sets required for several set sizes and spacings (Table XVIII).

BOLTING

Seed-stalk formation or bolting has always been a major problem in the growing of onions from dry sets. As an onion with a seed-stem is

TABLE XVIII

THE QUANTITY OF ONION SETS REQUIRED TO PLANT AN ACRE. DATA FOR NINE SPACINGS AND FIVE SIZES OF SETS

(Colby *et al.*, 1945)

Diameter of sets (in.)	Spacing between rows (in.)								
	12			14			16		
	Spacing between sets in the row (in.)								
	2·5	3·0	3·5	2·5	3·0	3·5	2·5	3·0	3·5
	Bushels per acre (1 bu. = 32 qt.)								
$\frac{1}{2}$	21·0	17·5	15·0	18·0	15·0	13·0	16·0	13·5	11·5
$\frac{5}{8}$	34·0	28·0	24·0	29·0	24·0	20·5	25·5	21·0	18·0
$\frac{3}{4}$	56·0	46·5	40·0	48·0	40·0	34·5	42·0	35·0	30·0
$\frac{7}{8}$	75·5	65·5	56·0	68·0	56·0	48·0	58·5	49·0	42·0
1	112·5	94·0	80·5	96·5	80·5	69·0	84·5	70·5	60·5

(*a*)—*above.* Land preparation for the onion crop in Upper Egypt After ploughing, the soil is pulverized thoroughly by hand to incorporate the new soil deposited by the Nile.

(*b*) Transplanting onions by hand in Shandaweel, Egypt Seedlings are set in a slanting position, and as the next furrow is made they are covered.

PLATE 26

Photos M. el Gammal

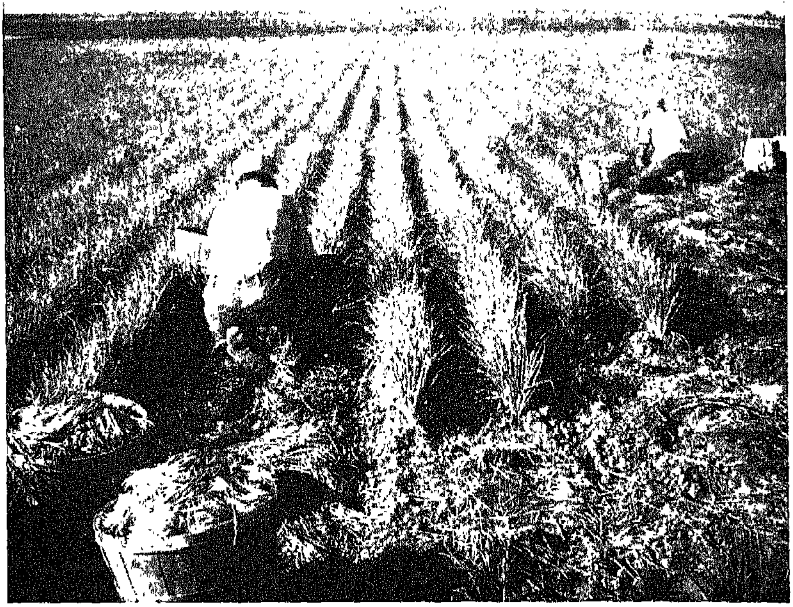


Photo U.S. Dep. Agric.

(*a*) Pulling 'Granex' plants for transplanting. The tops are twisted off to make transplants 5 to 6 in. long. Crystal City, Texas.

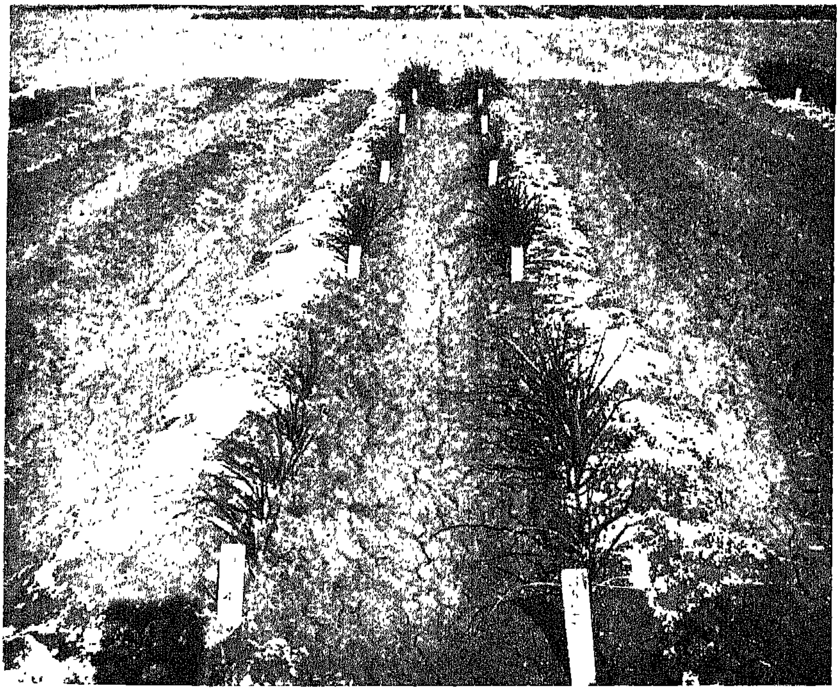
Photo Dessert Seed Co., Inc.

b) Onions being grown for the production of large bulbs. Onion seed was precision-planted in six rows on raised beds, and the weeds were controlled entirely with sulphuric acid; the rows are about 2½ in. apart. Blythe, California.

PLATE 27

(*a*) 'Granex' hybrid onions being grown as a winter dry-land crop, Mathis, Texas. The rows are spaced 3 ft apart, and before the harvest, either cotton or grain is drilled between them. At the left is a flowing oil-well, characteristic of this region.

Photos Dessert Seed Co., Inc.



(*b*) In many irrigated regions, high salt-concentration in the soil presents a special problem. By careful irrigation in the furrow adjacent to the plants, as shown above, the salt can be concentrated at the top of the bed, away from the growing plants. The beds are about $3\frac{1}{2}$ ft from centre to centre.

PLATE 28

Photo U.S. Dep. Agric.

(*a*) Growing onions on muck land in New York State. Muck soil can be prevented from blowing away by planting willow trees along ditch-banks, and by using snow fences at intervals between rows in the field. The fence is about 4 ft high.

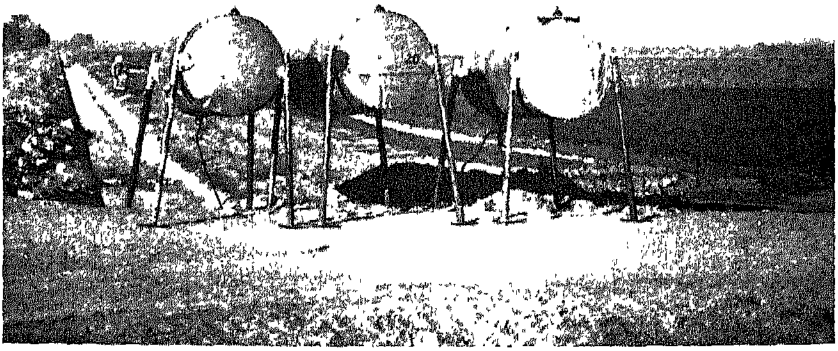


Photo Dessert Seed Co., Inc.

(*b*) Applying liquid fertilizer in the irrigation water. The rate of flow of fertilizer into the irrigation water is calibrated to give the required amount per acre.

PLATE 29

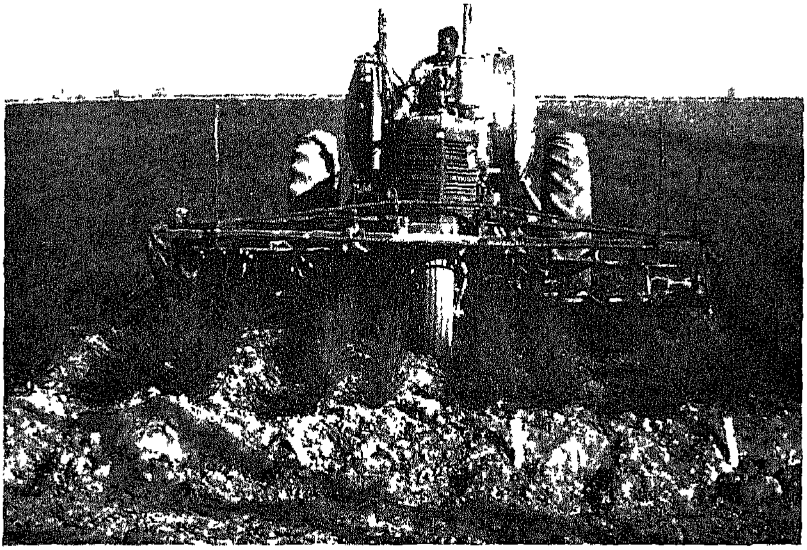


Photo Dessert Seed Co., Inc.

(*a*) Side dressing with liquid fertilizer. Applications are made 8 to 10 in. from the rows and 3 in. deep.

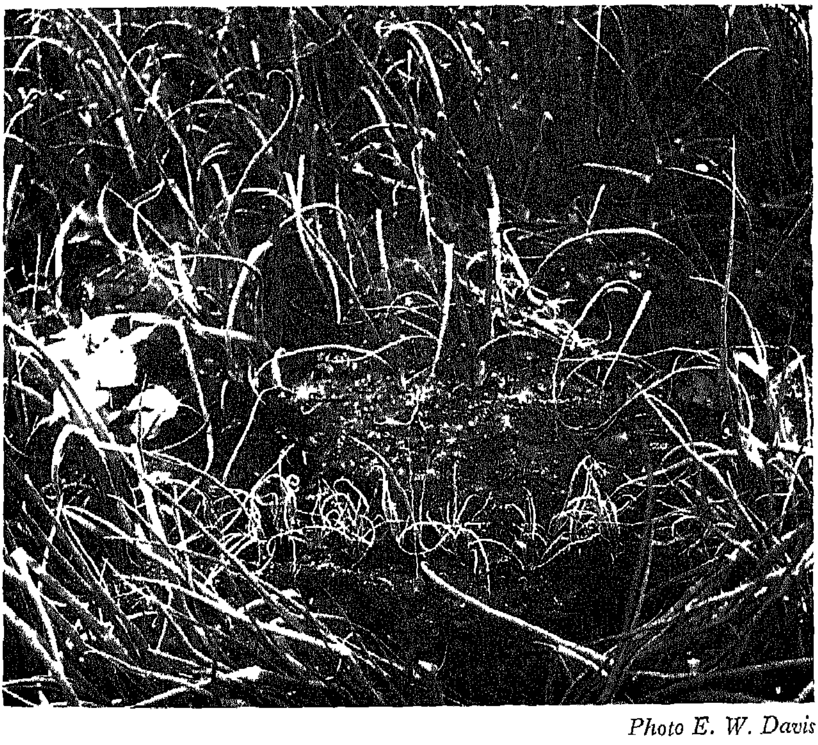


Photo E. W. Davis

(*b*) Zinc deficiency in onions. The dwarfing and other symptoms on the onion plants in the front-centre of this picture resulted from zinc deficiency in a row that was missed by the fertilizer applier. Muck land, Montello, Wisconsin.

PLATE 30

Photo Dessert Seed Co., Inc.

[illegible], and Tyme, green bunch onions in the field in southern California. [illegible] the foreground show how thickly the seeds were planted, and also the size of the onions at the time they are pulled for market.

Photo U.S. Dep. Agric.

[illegible] ripe onions in bushel baskets, Laredo, Texas. The bags beside the baskets will be used to haul the onions to the packing shed.

PLATE 31

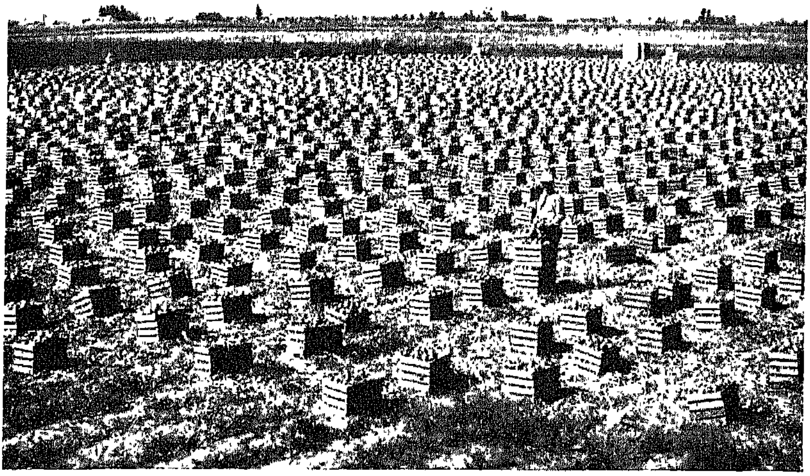


Photo D. F. Franklin

(*a*) Curing 'Sweet Spanish' onions in crates in southwestern Idaho. These slatted crates provide free circulation of air around the bulbs. Each crate holds about a bushel of onions.

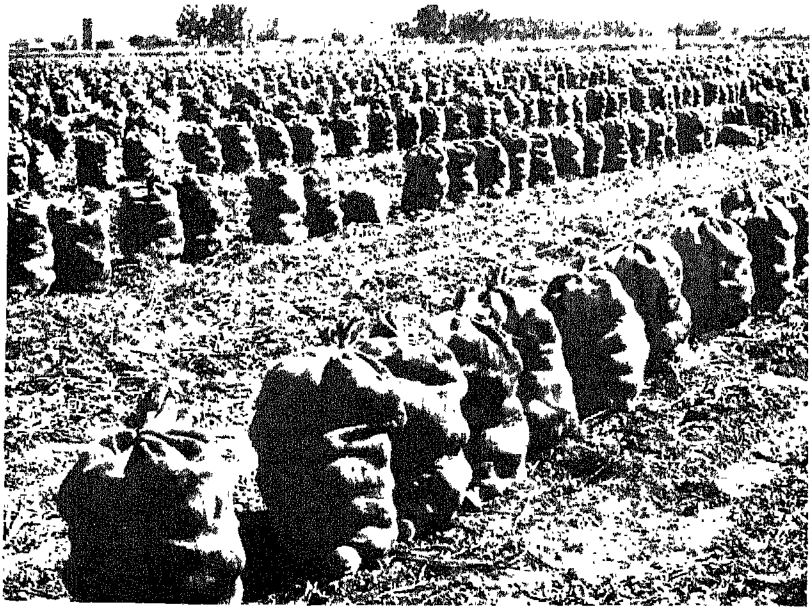
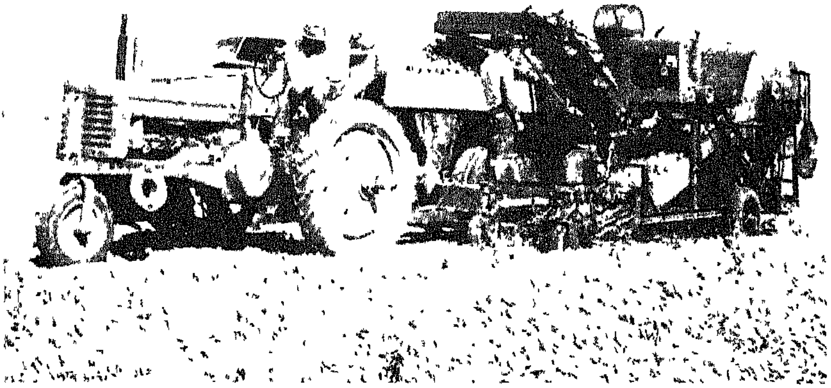


Photo Dessert Seed Co., Inc.

(*b*) Curing 'Sweet Spanish' onions in burlap bags, southwestern Idaho. These bags of onions weigh 100 lb.

PLATE 32



(*a*) Harvesting 'Sweet Spanish' onions in eastern Oregon with a blower-type machine Two rows are dug simultaneously The tops of the onions are cut off in the machine and are then blown out with the loose scales and other debris The bulbs are loaded in bulk in a truck which is driven alongside the machine

Photos Dessert Seed Co , Inc

(*b*) Stacking crates of 'Sweet Spanish' onions in the field in southwestern Idaho with a power-booster or lift The same machine is used to load crates on to a truck, take them off, and arrange them in the storage room. Twenty-four crates are handled at a time

PLATE 33

usually unmarketable because it has a hard core in the centre of the bulb and is subject to rotting, bolting must be held to a minimum. Bolting is influenced not only by growing conditions but also by storage temperature of the sets, size of set, and the cultivar used. Thompson & Smith (1938), in New York, studied the bolting of plants grown from several sizes of sets, and Beekom (1952), in the Netherlands, and Falkowski (1936), in Poland, made similar studies. A number of these papers, and others on storage temperatures for sets, have already been discussed in detail in Chapter IX.

Seasonal conditions, especially of temperature, have a tremendous influence on the amount of bolting. As a rule, bolting is much more severe in a cool spring than in a warm spring. If planting is delayed until the soil and air temperatures become warm, bolting is usually considerably reduced; but late planting reduces the yield and makes the crop mature somewhat later.

CULTIVARS

The choice of a circular is very important in the growing of onions from sets. The most important consideration is that the sets must keep well, as they usually need to be stored for 6 or 7 months. The cultivar should be free from a tendency to bolt, and it must be rapid-growing, early-maturing, and attractive. In the famous Mako district of Hungary, the Mako cultivar is used almost exclusively. In the United States the chief cultivar used is Ebenezer; but White Ebenezer, White Portugal (Silverskin), Golden Globe, and others, are grown occasionally. In a comparison of three cultivars, Thompson & Smith (1938) got the least bolting with Ebenezer, the most with Red Wethersfield, and an intermediate amount with Yellow Globe (Table X, p. 112).

GROWING LARGE BULBS BY DIRECT SEEDING

Direct seeding is probably the most economical method of growing onions, and it is done successfully on both muck and mineral soils. In the United States and Canada, most of the late crop for storage is grown on muck. Muck soil seems especially suited to onion growing; it usually has an ample moisture supply, it is relatively free from stones and debris, and its looseness permits easy emergence of the seedlings and later adjustment of the bulbs in the row so that they do not become malformed. However, the large 'Sweet Spanish' onions of the western United States are grown almost entirely on mineral soils.

Land preparation for transplants and sets has been discussed in the two preceding sections, and most of the details given there apply also to the direct-seeded bulb crop. As seedlings are usually not thinned, every effort must be made to secure a uniform stand at the desired density. In determining the most desirable rate of seeding, the percentage of germination, size of seed, cultivars, and spacing, should all be considered. Thus, for example, the large Sweet Spanish types are planted more thinly than the Yellow Globe storage types. The seeders used may plant a single row or as many as ten rows at once, and may distribute fertilizer below the row and insecticide in the row at the same time.

Short-day cultivars, grown as a winter crop, are often direct-seeded. Under furrow irrigation these are usually planted on raised beds, with two or more rows on a bed (Pl. 27(*b*)). The seed is often precision-planted in dry soil and then irrigated.

Short-day onion cultivars are sometimes grown inter-planted with other crops. In the Coastal Bend district of Texas, south of Corpus Christi, about 10,000 acres of onions are direct-seeded each year (Pl. 28(*a*)). These are planted in the autumn, in rows about 3 ft apart, at the rate of about one pound of seed per acre. Before the bulb crop is ready for harvest, the onion rows are inter-planted with cotton or grain. The cost of producing the bulb crop is low, as very little seed is used, there is very little outlay for weed control, and the crop is not irrigated. If prices are good, the grower makes a profit; if prices are poor, very little is lost, because not much has been invested.

Precautions must be taken when onions are direct-seeded on the saline soils that are present in many irrigated districts. Young seedlings are especially susceptible to salt injury. With furrow irrigation, several systems are used to lower the salt content around the germinating seeds and the young seedlings. A sloping bed may be used—so made that the centre of the bed is higher than the sides where the seed is planted. When irrigation water is applied, the salt moves to the high ridge between the rows. Another method is to irrigate every other furrow and to plant the seed only on the irrigated side of the bed, which is slightly lower than the unirrigated side (Pl. 28(*b*)). Salt accumulates on the higher, unplanted side of the bed.

Onion plantings on muck are often destroyed early in the season by strong winds blowing seed out of the soil, uncovering young seedlings, or injuring them with blown soil particles. Much of this injury can be prevented by growing tree windbreaks (usually willows), placing lath fences in the field (Pl. 29(*a*)), growing spring grains (such as rye, wheat, or barley) between the rows, increasing the fibre content of the soil, keeping the soil moist by overhead irrigation, or raising the water level where sub-irrigation is practiced. Any one or a combination of these methods may be needed to protect the crop.

IRRIGATING THE CROP

The most common method of applying water to the onion crop is to irrigate between the rows or beds. As water runs down the furrow, it replenishes the water supply in the soil below the plants. In recent years, light-weight aluminium piping with quick coupling devices has made overhead irrigation popular in many districts. Sub-irrigation can be practised on soils that allow a free movement of water below the surface, and a considerable acreage of onions is grown by this method in the Delta region of California, where the surface of the land is usually below that of the water in the surrounding streams. Here the water is siphoned and pumped from the streams into large irrigation ditches that carry it to a series of laterals extending through the field. The soils are open and porous, and when the water is raised in the ditches, the water-table is elevated throughout the entire soil area. After the water-table is raised to within a few inches of the soil surface, water is pumped back from the ditches into the streams, until the water-table reaches the desired depth. Often this method is supplemented by overhead irrigation.

In certain districts the onion crop may be produced entirely with irrigation water, but usually irrigation supplements rainfall. More often than not, a growing crop will benefit from irrigation during periods of deficient rainfall. At Davis, California, where the winter rainfall averages about seventeen inches, MacGillivray (1950) found that supplemental irrigation increased both yield and bulb size. He also found that insufficient soil moisture caused earlier maturity, but that grade, storage life, dry matter, drying ratio, and pungency, were not greatly influenced by irrigation. His data on yield are summarized in Table XIX.

At Storrs, Connecticut, during two years when rainfall in the summer growing-season was 14·3 in. (1952) and 8·8 in. (1953), Drinkwater & Janes (1955) grew two hybrid onions without irrigation and with three levels of added irrigation water. In both years, irrigation treatments increased total yields, but only in the drier of the two years was the yield of *U.S. No. 1* onions increased. Weight loss during storage was greater in the onions from the non-irrigated plots than from the irrigated plots. In both years, added irrigation water delayed maturity.

If the soil is dry, transplants should be irrigated as soon as possible after being set. Well-hardened seedlings will survive for twelve or more days after being transplanted to dry soil, but delayed irrigation results in lower yields. Roots continue to arise at the base of the plant while it is actively growing, but new roots do not grow out unless the zone from which they arise is in moist soil. The frequency of irrigation and the amount of water required depend on such factors as cultivar, soil type, season, amount of rainfall, and diseases; therefore, it is difficult to give definite recommendations. Over-irrigation, as well as under-irrigation, may lower yields. The foliage of over-irrigated plants has an unhealthy yellowish colour; if the surface soil rarely becomes dry, it is probably over-irrigated. Onions that receive just enough water will often yield better than over-irrigated crops. When the plants start to mature, irrigation should be discontinued and the soil allowed to dry.

TABLE XIX

IRRIGATION TREATMENTS AND YIELD OF ONION BULBS. YIELD MEASURED IN 50-LB. SACKS OF U.S. NO. 1 ONIONS PER ACRE

(MacGillivray, 1950)

Treatment	Irrigation water added (in.)	Irrigations (no.)	Cultivars		Irrigation water added (in.)	Irrigations (no.)	Cultivars	
			Grano sacks	Stockton Yellow Globe sacks			Aust. Brown sacks	Southport White Globe sacks
				1942				
Dry	0·0	0	426	419	0·0	0	102	102
Medium	6·6	3	620	719	10·6	4	236	214
Wet	11·2	6	653	885	18·9	9	297	287
L.S.D.,[1] 5% level			171	23			72	34
				1943				
Dry	0·0	0	203	101	0·0	0	71	130
Light	3·6	2	313	137	9·0	3	175	221
Medium	5·3	3	438	235	14·1	4	248	369
Wet	13·1	8	476	272	27·3	11	335	453
L.S.D.,[1] 5% level			51	6			56	74

FERTILIZERS AND NUTRITIONAL DEFICIENCIES

The soil pH should be within the range of 5·5 to 6·5, but good yields can be obtained with a slightly wider range of soil reaction. Most strongly-acid soils may be corrected by liming, and highly-alkaline soils can be improved by adding sulphur.

Because soils are of many types, and have different fertilizer and crop histories, it is impossible to recommend a definite fertilizer programme. As soil testing methods have become fairly reliable in some areas, it is advisable for growers to have soils tested for pH and for nutrient levels. Usually, a basic fertilizer application is given before the crop is seeded. With furrow irrigation, fertilizer is spread on the surface or drilled into the soil before the beds are made. A drill can place fertilizer in a wide band below the seed. Growers occasionally apply a portion of the fertilizer at planting time in bands 2 in. to 3·5 in. below the seed row. In tests at Shafter, California, with the transplant onion crop, Lorenz (1949) got the best results when the fertilizer was placed at transplanting time 3 in. directly below the row.

Late applications of nitrogen can be given either as a top or side dressing in pellet or granular form. Nitrogen can also be applied in the overhead irrigation system, in the head ditch in furrow irrigation (Pl. 29(*b*)), or as a liquid between the rows (Pl. 30(*a*)). Phosphate and potash should usually be applied at or before the time of planting. Besides nitrogen, phosphorus, and potassium, which are usually needed, it may be necessary to apply other elements such as copper, manganese, and zinc.

F. W. Zink (1962), working in the Salinas Valley of California, has made one of the few studies on nutrient absorption by onions. He determined the rate of growth (as measured by plant height, leaf number, and fresh weight) and of nutrient absorption (of N, P, K, Ca, Mg, and Na) during the development of a spring, a summer, and a winter crop of 'Southport White Globe' green bunching onions. The average absorption of elements, in lb./acre, for the three crops during their growing-season, was: N, 65·6 lb.; P, 9·4 lb.; K, 78·9 lb.; Ca, 27·5 lb.; Mg, 6·3 lb.; and Na, 7·5 lb. From planting until harvest, the three crops were in the field for 84 (spring), 75 (summer), and 136 (winter) days. Yields were somewhat above average for the area, so we may assume that the quantities of minerals absorbed were above the required minima. The rate of growth increased as the season progressed, especially for the spring and summer crops. Thus, these two crops added 44 and 56 per cent, respectively, of their fresh weight during the last week before harvest. Nutrient uptake also became more rapid as the season progressed; during the 21 days before harvest, the spring and summer crops removed in excess of 53 per cent of the total N, P, and K that they absorbed, and the winter crop in excess of 32 per cent of its total uptake. This type of analysis indicates clearly the growth periods during which nutrients are required in greatest amounts.

When any of the essential nutrients are not present in sufficient amounts in the soil, or are not available to the plants, deficiency symptoms develop. These deficiencies, which are exhibited in various ways, are described briefly below.

NITROGEN

According to Harmer & Lucas (1955), nitrogen deficiency in the field is shown by an erect growth of the leaves, which are pale-yellow or greenish-yellow in colour. Nitrogen deficiency symptoms may develop if the season is exceptionally wet, the soil poorly drained, or the temperatures low. Symptoms are more likely to develop where plants are crowded. An oversupply of nitrogen early in the growing period may cause an excessive top development, especially if other conditions for growth are favourable. Stuart & Griffin (1946) described onion plants which had been grown in nutrient solutions that were low in nitrogen. The plants grew slowly, became stiff and upright in habit, and developed short, narrow leaves of a very light-green colour. Later the tips of the older leaves died and became bleached and yellow.

PHOSPHORUS

Harmer & Lucas (1955) state that phosphorus deficiency in the field results in slow growth, delayed maturity, and a high proportion of thick necks. If applied in bands below the row, phosphorus remains more available than when it is disked into the soil, and thus hastens maturity. Harmer & Lucas recommend a mixture high in phosphorus for alkaline and poorly-drained soils. Stuart & Griffin (1946) describe the first phosphorus deficiency symptoms of onions in nutrient solution as a wilting and death of the tips of the oldest leaves. These leaves soon become mottled and necrotic in appearance, with green islands appearing among yellow and brown tissue as the necrosis advances towards the leaf-base. When dead, the leaves turn black.

POTASSIUM

When potassium is deficient, according to Harmer & Lucas (1955), the tips of onion leaves turn brown and die back, producing symptoms that are very similar to the die-back caused by copper deficiency. These authors claim that potassium remains in a water-soluble condition when applied to muck soil and is leached out during excessively wet periods; therefore, additional applications may be necessary during periods of heavy rainfall. Stuart & Griffin (1946) described the earliest deficiency symptom as a slight yellowing of the oldest leaves; this was followed by wilting and death of the leaf tips, particularly on the upper surface. The wilted parts had a satiny texture, and their entire leaf drooped, remained somewhat inflated, gradually assuming a crêpe-paper-like appearance, and then became about the same colour as leaves that were deficient in nitrogen. In Poland, Chroboczek (1936) found that lack of potassium under field conditions produced plants with dark-green tops, gave low yields (of soft bulbs with thin skins), delayed maturity, and lowered keeping quality. Beekom (1952), in the Netherlands, showed that a deficiency of potassium caused an increase in the percentage of thick necks and also lowered the storage quality.

COPPER

Copper deficiency has been reported as occurring most often on muck and peat soils. Knott (1933), in New York State, found that onions on copper-deficient soils had thin, light-coloured scales, which detracted from their appearance. Yellow scale colour was intensified, and scale thickness increased, by adding 200 to 400 lb. per acre of powdered copper sulphate to the soil and disking it in before planting. On muck soils where potatoes are grown in the rotation, sufficient copper is usually applied to the soil in the fungicide Bordeaux mixture. Browne (1950) reports that in southwestern Quebec, Canada, onion yields are depressed as much as 30 per cent by lack of copper, and that addition of copper is necessary if satisfactory skin colour and maturity are to be obtained. Harmer & Lucas (1955) report that copper, applied in an available form, is likely to increase greatly the yield, and improve the quality and colour, of onions on all acid muck soils and to some extent on alkaline mucks. Furthermore, the benefits from copper are much more evident in a hot, dry season than in a cool, wet season, and are greater on well-drained than on poorly-drained mucks.

MANGANESE

Manganese deficiency is most likely to occur in highly-alkaline mucks. Knott (1939) reports manganese deficiency on muck soils. It was especially prevalent where the soils had been over-limed, where stumps or the peat had been burned, or where the peat was shallow and underlain with marl. Deficiency symptoms in the field, according to Harmer & Lucas (1955), are a curling of the leaves, slow growth, light colour of foliage, delayed bulbing, and thick necks. Manganese deficiency can be corrected by applications of manganese sulphate or elemental sulphur to the soil; the latter is more economical and more lasting in its effect. Onion leaves will absorb manganese rapidly when it is applied as a spray or dust. Manganese sulphate can be applied in water-soluble form at the rate of from 1 to 5 lb. in 100 gal. of water, the larger amount being used on the more alkaline soils. Nylund (1952) increased onion yields by applying 100 to 150 lb. of manganese sulphate per acre, broadcast before seeding; about the same increase was obtained by applying 30 lb. of manganese sulphate as a foliar spray.

Lingle & Wight (1961) report that onion growth may be slowed by manganese toxicity. Symptoms are similar to those of nitrogen deficiency—i.e. burning of the leaf tips. This malady is usually associated with strongly acid (pH 4·0 to 5·0) soils, but may be associated with a high rate of nitrogen application.

ZINC

Zinc deficiency seems to be fairly common, especially in muck soils when they are first broken, and in soils of high pH (7·5 to 8·0) in the western United States. The symptom reported by most observers is a distinct dwarfing of the plants (Pl. 30(*b*)). J. C. Lingle (unpublished data) describes the main deficiency symptom in the field as a distinct corkscrewing of the leaves or, in mild cases, a general outward bending of the leaves, which gives them a flattened appearance. This response is accompanied by an irregular orange splotching of older leaves and a very faint interveinal chlorosis of younger leaves. Zinc deficiency can be controlled by a zinc sulphate spray applied to the leaves with a sticker to enhance absorption, or by zinc sulphate applied to the soil.

BORON

Boron deficiency is seldom encountered under field conditions. Stuart & Griffin (1946) report that, in nutrient culture, boron deficiency gives onion plants a characteristically stunted, distorted appearance.

Leaf colour varies from dark grey-green to deep blue-green, the youngest leaves developing conspicuous yellow and green mottlings. Shrunken areas appear, followed by ladder-like transverse cracks, on the upper surfaces of the basal leaves. The leaves become stiff and brittle. Boron is needed only in minute quantities, and in most soils the supply is adequate. Where boron is deficient, borax is applied at the rate of 5 to 20 lb. per acre.

GROWING GREEN ONIONS

Green onions are those that are pulled while the tops are still green and usually before a large bulb has formed. Many different kinds of onions are so used—non-bulbing as well as bulbing types. The latter can be harvested at any stage of bulb development, but generally the young, tender plants are preferred. If we consider green onions on a world-wide basis, their consumption would probably approach that of mature onions, although it is difficult to get reliable estimates. In some countries, such as China, green onions are used much more extensively than bulbs.

THE COMMON ONION (*Allium cepa*, Common Onion Group)

Most of the green onions in America and Europe are cultivars of the common onion. Both sets and seed are used for their production.

Sets. The easiest method of growing green onions is from dry sets. This is the method most often used by the home gardener. The sets, usually after storage for 6 to 7 months, start growth as soon as they are planted in early spring. Sets about ¾ in. or less in diameter are planted 1 to 2 in. deep and spaced 2 to 3 in. apart in rows 12 to 18 in. apart. Colour is not important in the home garden but, when plants are grown for market, white sets are generally used. The white cultivar that is most commonly used in the United States is White Portugal. Short-day-type onions are not used to any great extent as dry sets.

According to Tiessen & Dickson (1959), green onions for winter use in Canada are produced from bulbs that have been forced in the greenhouse, cold frame, or hotbed. The smaller mature bulbs from storage are planted close together, almost touching one another. The forcing room is maintained at 60° to 65°F. and water is applied when needed. When the shoots are of marketable size, the bulbs are cross-sectioned with a knife, slightly below the centre. The lower half of the bulb remains in the soil to produce a second crop; the upper half is stripped away from the shoots when the latter are prepared for market.

In the United States, when the price for the early white onions from Texas is low, northern growers sometimes buy the small bulbs, hold them for several months, and plant them for the production of green onions.

Direct Seeding. Most of the green bunch onions for market are obtained by direct-seeding of the cultivars of *A. cepa*. In the United States, thousands of acres of onions are grown each year for the green-bunch market and some are being harvested somewhere throughout the year. In the winter they are grown in a number of districts in the southern States, the main centre of production being around Phoenix, Arizona. During summer, harvesting follows the season northwards. The best districts are those that are free from foliage diseases and freezing injury.

Seed is sown rather thickly—as much as 20 to 30 lb. per acre. An abundant supply of fertilizer and water produces tender plants with dark-green, fresh-looking tops. When sufficiently large, the plants are pulled and tied in bunches in the field, then hauled to the packing shed and washed under high-pressure sprays. They are then packed in crates lined with wax paper, layers of bunched onions alternating with crushed ice.

The United States trade usually demands a white onion that is firm, with a long shank and little or no bulb. The tops must be dark-green, not too course, upright, and free from mechanical injury (Pl. 31(*a*)). For marketing, the tops may be clipped or left intact. Plants are often marketed with the roots attached, and therefore these must be white and free from disease.

The White Lisbon is probably grown more than any other cultivar for green bunching. It is used in England and many other European countries. In the United States, the long-day cultivars White Lisbon, White Sweet Spanish, and Southport White Globe, are used extensively, but short-day types such as Crystal Wax are sometimes grown as a late autumn and winter crop. Occasionally, green bunch onions are obtained by thinning the early crop of Crystal Wax-type onions, which are being grown for bulbs. In some countries, such as Australia and Mexico, white onions may be bunched when the bulbs reach a diameter of from 2 to 3 in.

Reference to the paper of Zink (1962) on growth and nutrient absorption by bunching onions has been made on page 131.

EGYPTIAN OR TREE ONION (*A. cepa*, Proliferum Group)

Despite its name, this onion is not found growing in Egypt. It does not produce seed but is propagated by top-sets that are formed in the inflorescence, and by divisions of the plant. It is winter-hardy; if planted in early autumn, the plants make good growth before freezing weather sets in, and growth is resumed in the spring as soon as the frost is out of the ground. Consequently, it can be pulled for green onions before those which are grown from bottom sets. In the United States this onion was grown rather extensively in the early days, especially in the northern part of the country, in both home and market gardens; in recent years, however, its cultivation has declined.

POTATO ONION (*A. cepa*, Aggregatum Group)

When the rather large bulbs of the potato onion are planted, they form a number of shoots which can be used for green onions; or if they are allowed to mature, they form small dry onions which can be used for propagation. Potato onions are used to some extent in England, Finland, and other North European countries, and in the home garden in mountainous regions of Kentucky, Tennessee, West Virginia, and Arkansas. The bulbs are usually planted in the autumn, and the green onions are pulled early in the spring.

JAPANESE BUNCHING OR WELSH ONION (*A. fistulosum*)

There are many cultivars of this species that have been used for centuries in eastern Asia; now their distribution is practically world-wide. Many cultivars exist in China and Japan, their numbers probably almost equalling those of *A. cepa*. When the Chinese and Japanese emigrated to other countries, they took forms of this onion with them, and it is often found growing in their gardens. The species is non-bulbing, prolific, hardy, and resistant to pink-root, smut, and yellow dwarf. For a fuller discussion of this interesting species, *see* Chapter XIX, pp. 237–241.

SHALLOTS (*A. cepa*, Aggregatum Group, and *A. cepa-fistulosum* hybrids)

In the United States, about 90 per cent of the shallot production for green onions is localized in southern Louisiana. Nearly all commercial shipments are made from early October to early May, and they may reach 1,000 railway carloads. During the spring months, most of the shallots are shipped in railway cars together with other vegetables.

According to Montelaro & Tims (1950), planting stock is obtained in Louisiana by selecting disease-free bulbs from storage for planting in the field between September 20th and October 30th. Bulbs are subdivided, and the sets are spaced 8 to 10 in. apart in rows which are 3·5 to 4 ft apart and about ⅛ to ¼ in. deep. Ten to fifteen days before planting, fertilizer is applied below the ridge and mixed well with the soil. By December 15th to January 30th, plants are ready for transplanting. Only healthy clumps are divided, and one large plant or two small plants are set in each hill. Cultural practices are similar to those used with dry sets. In May, when the plants have matured and their tops have fallen over, the crop is lifted. After the plants have dried in the row for a day or two, they are placed in shallow trays for 3 to 4 weeks to cure, and are then stored over the summer in a dry, well-ventilated building.

For production of the commercial crop of green shallots, bulbs are removed from storage in late August and divided, the sets being graded into large, medium, and small sizes. Plants from the large sets reach marketable size first, so are planted in late August or early September for the early harvest. The medium-sized sets are used to grow an early crop for shipping, and to produce additional plants for transplanting to new fields for later harvest. For transplants, only healthy, vigorous clumps should be used. Shallots should not be grown on the same land more than once in 3 or 4 years, and then should follow a legume crop, such as soybeans, which has been turned under.

Blanching is started about 5 weeks before pulling of the crop for market. At first about 2 in. of soil is banked about the plants, and in from 2 to 3 weeks another 2 in. of soil is added.

For market, shallots are pulled, skinned, washed, and tied in bunches. Usually they are packed in crates lined with wax paper, the layers of bunches being alternated with crushed ice.

The leading commercial cultivars in Louisiana are Louisiana Pearl and Bayou Pearl. A more recent introduction, Delta Giant—an *A. fistulosum*-shallot amphidiploid back-crossed to shallot—is prolific, tolerates hot weather, and therefore can be grown both earlier and later than the *Allium cepa* cultivars Louisiana Pearl and Bayou Pearl. It is resistant to pink-root and certain foliage diseases. For the years 1956 and 1957, marketable clumps per acre averaged about 9,000 lb. for Delta Giant and about 4,000 lb. for Bayou Pearl. Another cultivar, Louisiana Evergreen, a highly pink-root-resistant F_1 hybrid between *A. fistulosum* and shallot, is not used for shipping but for growing in the home garden all the year round as a green shallot. It does not form a bulb but continues to divide throughout the year.

XII

HARVESTING AND POST-HARVEST HANDLING

MANY operations are performed in getting a mature onion crop from the field to the consumer, but we shall discuss here only the major ones of harvesting, curing, grading, storing, and transportation. These operations vary from country to country, from district to district, and even from farm to farm; but, in general, practices which are found most suitable for a region are followed there rather consistently. We consider harvesting in the somewhat limited sense of getting the crop out of the soil, and curing as the drying process that is applied to bulbs to improve their keeping in transit and storage. Harvesting and curing are frequently quite distinct, especially when the bulbs are cured artificially; but they may be continuous or simultaneous operations in the field. Grading is especially important when onions are to be shipped some distance to foreign or domestic markets. Conditions for good storage and transportation are much alike; they must keep the onion attractive, dormant, and free from disease.

Harvesting and Curing

HARVESTING

In many commercial onion-growing areas, cultivars can be so chosen and grown that they reach maturity in warm dry weather that is favourable to harvesting operations. As onions reach maturity, they cease to produce new leaves and roots, the food still present in the leaves moving into the bulbs; the tops, while yet green, weaken just above the bulb, and fall to the ground. All the plants in a field do not mature at the same time, and, as a general rule, harvesting is best begun when one-quarter to one-third of the tops have fallen over. But many factors may modify this practice, such as price, weather, condition of the crop, and immediacy of consumption. Consequently, the farmer may wish to know what problems are likely to accompany an advance or delay in harvest.

Bulbs that are harvested when they are too immature may take longer than others to dry properly for storage, and, if the necks are not yet soft, the inner leaves may still be growing and will continue to elongate from the topped bulbs, yielding an unsightly product. As food moves from the tops into the bulbs during maturation, bulbs that are harvested early may never become smooth and firm, and yields from such early harvests are usually smaller than from later harvests. On the other hand, onions that are left too long in the field may sunburn and, especially if subjected to heavy dews or rain, may lose their outer scales, becoming less attractive. Also, late-harvested bulbs may keep poorly in storage, because rot organisms appear to infect bulbs more easily as they mature.

Harvesting operations vary greatly—from hand pulling without removal of either tops or roots, to machine operations in which the bulbs are pulled, topped, and moved from the field to storage without being touched by hand. In firm soils where pulling is difficult, the onion roots can be cut just below the bulbs, by using a knife fastened horizontally to a sled. This is easily done if the onions are grown on raised beds. The bulbs may be pulled immediately after such cutting, or they may be left for a day or two to dry. In peat or other loose soils, there may be no need to cut the roots for either hand or machine harvesting. Tops and roots may be removed either at the time of pulling or after the plants have been allowed to dry. Occasionally the bulbs may be stored with the tops on. As harvesting procedures vary in different parts of the world, and are closely associated with curing practices, they will be illustrated by several examples, following a discussion of curing.

Experimental studies of harvesting practices have been relatively few. One by G. N. Davis & Jones (1944), relating time-of-pulling (maturity) to yield, is of general interest. Triplicate plots of 'California Early Red' onion were used. Pulling was started on June 3rd, when about 12 per cent of the tops had fallen over, and was continued at 4- to 5-day intervals thereafter. The plants were dried in shallow trays, the tops

TABLE XX

EFFECT OF HARVEST DATE ON MEAN WEIGHT PER BULB AND YIELD PER ACRE, FOR THE CULTIVAR CALIFORNIA EARLY RED

(G. N. Davis & Jones, 1944)

Date harvested	Bulbs harvested per plot (no.)	Tops down (%)	Mean wt. per bulb (lb.)	Yield per acre (100-lb. bags)
June 3rd	133	12·3	0·37	296
June 8th	133	26·5	0·42	355
June 13th	133	45·6	0·42	343
June 17th	130	76·9	0·47	364
June 22nd	133	87·3	0·48	388
June 27th	125	94·6	0·45	342
July 2nd	130	100·0	0·51	401
July 7th	131	100·0	0·51	404
July 12th	136	100·0	0·52	430
L.S.D.[1] at the 5% level	N.S.[2]	9·3	0·04	34
L.S.D.[1] at the 1% level	N.S.[2]	12·8	0·06	47

[1] Least significant difference.

[2] Not significant.

removed, and the bulbs weighed 10 days after pulling. Yield per acre increased throughout the experiment, even after about 90 per cent of the tops were down (Table XX). During the 10-day curing periods, climatic conditions were not uniform, and the lots exposed to strong desiccating winds lost more weight than the others.

The data of Colby *et al.* (1945) confirm these yield changes with maturity, and in addition show that infection by rot organisms may increase with time when such maturing bulbs are left in the field. These authors showed that 'Ebenezer' onions, grown from dry sets and harvested when 50 per cent of the tops were down, had lost an average of about 12 per cent of their weight from decay by October 20th. Bulbs that were harvested 10 days later, when all the tops were down, had an average loss of 18 per cent. The fully matured bulbs, however, yielded 20 per cent more at harvest-time, which more than compensated for the greater losses in storage.

CURING

Before onion bulbs are placed in storage or marketed, the tops are usually removed, and frequently also the roots. Removal of the tops, especially if the necks are not dry, provides an open, moist surface where rot organisms can easily enter. These neck tissues, and all other moist surface tissues of the bulb where rot organisms might become established, should be carefully dried before infection can occur. This drying procedure is known as curing. Onions that are sold for immediate consumption may need no curing at all, but curing is usually essential if bulbs are to be stored or shipped over long distances.

In areas such as the south-west United States and Upper Egypt, where the relative humidity is low and rains seldom occur during the harvest season, curing is easily and effectively done in the field. As the onions are pulled, several rows may be placed together into windrows, with the green tops covering the bulbs to prevent sunscald. White onions, especially, need good protection from the sun. During good drying weather, the tops and roots may be clipped off with a sharp knife or sheep shears immediately after pulling, and the bulbs placed to dry in windrows or in baskets or crates (Pl. 31(*b*)). If the onions are fairly mature, the relative humidity is low, and the air movement is good, it is not unusual to pull, clip, and ship during the same day. Even under relatively dry conditions, however, it is often advantageous to dry onions artificially. Hoyle (1948) found that artificial drying for 16 hours with a blast of air heated as high as 118°F. did not injure the bulbs; it speeded up the curing time and in general was quite satisfactory. According to Vaughan & Cropsey (1958, 1959), the Sweet Spanish cultivars are injured when artificially dried at 125°F. for more than 24 hours. Drying at 115°F. for 24 hours reduced the amount of neck-rot in storage; but if drying at this temperature was continued for more than 48 hours, the amount of decay increased. Vaughan & Cropsey found that crates were superior to bags for field curing and for storage. In a moderately moist area, Colby *et al.* (1945) found that field curing in piled crates was better than field curing in burlap bags or in windrows.

Lorenz & Hoyle (1946), at Davis, California, compared curing of topped and untopped bulbs. The onions were harvested when the tops were still green, but the necks were softening and some of the tops were down. The bulbs without tops lost about 3 to 5 per cent of their original weight after 3 days of curing, and about 8 per cent after 9 days of curing. Bulbs with tops lost more weight during the first few days of curing than bulbs without tops, which indicates that the tops were removing water from the bulbs. At the same time, there was a movement of soluble solids into the bulbs from the attached tops, and the gain in dry-weight of the bulbs was of the same magnitude as the dry-weight loss from the tops.

EXAMPLES OF HARVESTING AND CURING PRACTICES

The following examples from several onion-producing areas of the world indicate the extent to which harvesting and curing are often parts of a continuous operation and depend on many factors, such as cultivar, soil, weather, and utilization of the product.

The method of harvesting and curing late onions in the United States varies somewhat with the district, the soil type, and the kind of onion. In the large onion-producing districts of the North, a hard, Yellow Globe type of onion, grown for storage, is produced chiefly on loose peat soils which make mechanical harvesting possible. Although different types of machines are used, in most cases a knife or shovel cuts under the bulbs and at the same time lifts them on to an endless steel-rod conveyor that sifts out the soil and carries the onions to another belt, which moves them over a strong blast of air, making the tops stand erect. While the tops are in this erect position, they are cut off by a rotary blade, or by a power-operated sickle similar to the cutting bar on machines for mowing hay or grain. The bulbs are then carried to crates or pallets on trucks that move alongside the harvester; or the onions may be run directly into trucks and hauled in bulk to the storage house. Some growers top the onions at the storage house, as the bulbs go either into or out of storage. These growers claim that the leaves give some useful protection against bruising, and that a rigid topper on a cement platform causes less injury to bulbs than a topper which is moving through the field.

Many of the Yellow Globe storage-type onions do not receive any field curing; instead, they are piled in bulk from 8 to 14 ft deep on slatted floors in the storeroom in bins, where hot air is blown through the pile until the necks are thoroughly dry. Although many of the smaller growers pull by hand and cure in the field in crates or bags, the trend among the larger growers is to do most of the curing in bins.

In the Sweet Spanish onion-growing districts of the western United States, machines are being perfected that will handle these large and rather soft onions without injury (Pl. 33(*a*)). The bulbs are undercut, allowed to wilt for 3 to 6 days, and then harvested by machine. However, many fields are still pulled by hand and topped at once into slatted crates or burlap bags, and left to cure in the field before storing (Pls. 32(*a*), 32(*b*)). Power equipment may be used for stacking crates in the field, for loading trucks, and for arranging crates in the storage house (Pl. 33(*b*)).

In southern Texas, where most of the early onions of the United States are grown, harvesting is usually started when the necks become soft and when 30 to 50 per cent of the tops are down. Most commercial growers do not wait for the crop to mature fully, but pull when the bulbs have reached their maximum size and while the tops are still green.

In Upper Egypt (Pl. 34(*a*)), harvesting of the crop for export usually starts in the last week of February. The bulbs are pulled when near their maximum size but while the tops are still green. The tops and roots are removed with a knife that is fastened at right-angles to a handle which is stuck in the soil.

In certain districts of Cape Province, South Africa, onions are braided into bunches. This is done after some drying, and to prevent the leaves from breaking they are moistened by a light sprinkling of water. Twine is braided with the leaves, to give strength. The bunches, which vary in length from 2·5 to 3·5 ft, are hung in well-aerated barns and sold during the winter and early spring.

In the early-onion districts of Japan, onions are harvested when the tops are still green. If the onions are to be sold immediately, the tops and roots are clipped and the bulbs are marketed in inexpensive straw bags (Pls. 34(*b*), 35(*a*)). Onions to be stored are tied in bundles (Pl. 35(*b*)), cured in the field for one day, and then taken to storage huts where they are hung on bamboo poles (Pl. 35(*c*)).

STORAGE

IN most countries, onions are in storage at some season of the year, regardless of whether they are produced as a summer or a winter crop. When grown as a summer crop, they are harvested in late summer and early autumn, and the crop is stored during the winter at low temperatures. When grown as a winter crop, bulbs may have to be stored during the summer under rather high temperatures. In most countries where summer storage is necessary, cold storage is not easily available and, even if it were, would be too costly to employ at all widely. In India, Egypt, and many other countries, the cost of storage must be held to a minimum.

Many factors influence the storage life of an onion. Under all storage conditions, onion bulbs continually lose water and dry matter, but the more serious losses arise from storage rots and from sprouting and rooting. Among the factors which are critical for successful onion storage are: choice of cultivar; methods of culture, harvesting, and curing; control of temperature and humidity in storage; design of storage structures; and use of sprout-inhibiting chemicals.

CULTIVARS

Extensive studies have been made in many countries to determine the keeping quality of various cultivars. Magruder *et al.* (1941) made a study of the principal onion cultivars of the United States grown in many soils and climates, and stored under a variety of conditions. They found that, regardless of how the onions were grown and stored, the various cultivars usually assumed about the same relative position as to storage quality. Magruder *et al.* were able to classify the cultivars which they studied into five storage groups as follows: very poor—Italian Red; poor—Crystal Wax, Yellow Bermuda, Early Grano; fair—White Sweet Spanish, Prizetaker, Sweet Spanish; good—Red Wethersfield, Mountain Danvers, Extra Early Yellow, Yellow Danvers Flat, Yellow Strasburg, Southport White Globe, Southport Yellow Globe, Southport Red Globe, Ohio Yellow Globe, White Portugal, Ebenezer, Yellow Globe Danvers; very good—White Creole, Red Creole, Australian Brown.

We know that in Louisiana the 'Red Creole' is successfully stored during the summer under high temperatures and in rather humid conditions. In California, South Africa, and Australia, the hard-fleshed, tough-skinned 'Australian Brown' is outstanding in storage qualities. 'Giza No. 6' was developed by the Ministry of Agriculture in Egypt to carry over the hot, dry summer and to stand rough handling and long-distance shipment. 'Pukekohe Longkeeper' excels all others in keeping quality in New Zealand. 'Mako', produced in Hungary, is known as an excellent storage onion.

CULTURE, HARVESTING, AND CURING

Regardless of the cultivar, in order to store well, an onion should mature normally. The neck should soften and the top fall over while the plant is in a healthy, growing condition. This softening occurs as the bulb matures; as leaf growth ceases and no new leaves are pushed into the neck region, the old leaves dry and shrink, effectively sealing the bulb neck. If premature death of the leaves is brought about by a severe thrips attack, downy mildew, or purple blotch, the plant continues to produce new leaves and forms a large, thick neck which holds the top erect. These thick necks do not shrink on drying, and such bulbs do not keep well in storage. Cultural practices may also affect the ability of the bulbs to keep in storage. Thus excessive applications of nitrogen late in the growing-season, or growing long-day cultivars under short-day conditions, will produce bulbs with thick necks. Cutting roots too soon and breaking over the tops to hasten maturity are not good practices if onions are to be stored. Finally, any of the conditions which interfere with good curing practices, as discussed above, will shorten the storage life of the bulbs.

STORAGE TEMPERATURE

One of the most critical factors in onion storage is temperature. Wright *et al.* (1935) stored Yellow Globe storage-type onions at 32°, 40°, and 50°F., and at relative humidities of approximately 65, 80, and 90 per cent. They found that sprouting in storage was influenced very little by humidity, but increased with each increase in temperature, whereas rooting increased with humidity and was little influenced by temperature. To keep bulbs in a sound, dormant state, they recommended storage at 32°F. and at a relative humidity of 64 per cent.

In India, Karmarkar & Joshi (1941) conducted storage tests with a red cultivar grown in the Bombay region. They used 8 different temperatures between 32° and 90° to 95°F.—a much wider range than was used by Wright *et al.* Samples of 20 bulbs, with each bulb weighing about 70 gm., were kept in small trays and weighed monthly to determine their losses. At all temperatures there was a gradual loss in weight; the loss at 90° to 95°F. was roughly twice that at 32°F. Sprouting occurred in the second month in onions stored at 48°, 52°, and 68°F. These temperatures seemed to be the ones that stimulated the most active vegetative growth. Sprouting first occurred at 40°F. (in the third month), then at 35°F. (in the fourth month), and finally at 32°F. (in the seventh month). There was no sprouting at 75° to 85°F. after 9 months, or at 90° to 95°F. after 10 months. In unsprouted onions the loss in weight is chiefly due to water transpired through the scales; in sprouted onions it is from water transpired by sprouts and scales. These studies show that onion bulbs can be stored at temperatures of 75° to 85°F. or higher over a period of 5 or 6 months without sprouting and without excessive loss of weight. In many countries, temperatures as high as or higher than these, prevailing over a period of several months, make storage entirely feasible. As we know that different cultivars respond differently to high-temperature storage, there is great need to develop better storage types for tropical and subtropical conditions. This is a project of far-reaching importance.

In another experiment, Karmarkar & Joshi (1941) determined the effect of storage at 32°F. and 90° to 95°F. on the subsequent rate of sprouting at 52° and 68°F. After being stored at 32° or 90° to 95°F. for 1, 3, 5, and 7 months, 25 bulbs from each temperature were placed at 52° and 68°F. In general the onions that had been stored at 32°F. sprouted much sooner after removal from storage than those that had been stored at 90° to 95°F. (Table XXI). Bulbs that have been stored for 5 to 6 months at 32°F. must be moved into consumer channels rather quickly to prevent excessive losses from sprouting.

TABLE XXI

SPROUTING OF ONION BULBS REMOVED TO 52° AND 68°F. AFTER 1 TO 7 MONTHS OF STORAGE AT 32° AND 90° TO 95°F.

(Karmarkar & Joshi, 1941)

Storage at 32°F.

Days at 52°F. following storage	Months at 32°F.				Days at 68°F following storage	Months at 32°F.			
	1	3	5	7		1	3	5	7
	% Sprouting					% Sprouting			
3	0	0	4	48	3	0	0	56	64
7	0	0	68	80	7	0	8	88	88
10	0	12	88	92	10	0	36	92	88
14	0	28	96	92	14	0	44	92	92
22	12	40	100	—	22	4	52	96	—

Storage at 90°–95°F.

Days at 52°F. following storage	Months at 90°–95°F.				Days at 68°F. following storage	Months at 90°–95°F.			
	1	3	5	7		1	3	5	7
	% Sprouting					% Sprouting			
3	0	0	0	0	3	0	0	0	0
7	0	0	0	0	7	0	0	0	12
10	0	0	4	48	10	0	0	0	44
14	0	0	20	56	14	0	0	12	52
22	0	0	68	88	22	0	12	48	68

Yamaguchi *et al.* (1957) and Pratt & Morris (1958) report an experiment in which 'Southport White Globe' onions were stored at 11 constant temperatures between 0° and 40°C. at uncontrolled but moderate humidities. After 4 months of storage, the number and weight of usable bulbs were recorded. Storage at 10°, 15°, and 20°C., gave the poorest results, the yield of usable bulbs being better at temperatures above and below this range. At the end of storage the bulbs from 0° and 7·5°C. had a fresher appearance than those from 25° to 35°C.; 40°C. appeared to be injurious. Yamaguchi *et al.* add, 'Many yellow centers, indicating sprout initiation, were found in onions stored at 10 and 15 degrees C. None were found at 25 degrees and higher, and relatively few at temperatures below 10 degrees.'

The observations of Karmarkar & Joshi (1941) and Yamaguchi *et al.* (1957) raise some interesting physiological problems—those of rest and dormancy in onion bulbs. An onion bulb which is neither sprouting nor rooting is said to be dormant. It may be dormant simply because its surroundings are too dry or too hot or too cold for root and sprout growth. But most well-matured onion bulbs fail to sprout immediately after harvest, even under conditions that are favourable for rooting and sprouting. Such bulbs, which are dormant because of *internal* factors, are said to have *internal dormancy* or to be in *rest*. H. A. Jones (1921), by periodically removing bulbs from storage and planting them, demonstrated that this condition of rest disappeared with time, for the bulbs sprouted and rooted more quickly the longer they were held in storage. From general observations it also appears that the period of rest varies greatly among cultivars. If, as in garlic (Mann & Lewis, 1956), the bulbs of onions lose rest more slowly above 20°C. than at temperatures of 15° to 20°C., we could easily explain the lack of sprouting at high temperatures observed by Karmarkar & Joshi (1941) and Pratt & Morris (1958).

Answers to a number of these questions have been explored in a recent study by Abdalla (1962). Abdalla observed, in 'Excel' onions grown in the spring from seed at Davis, California, that leaf initiation continued from the time of germination until about 20 days before maturity, i.e. 20 days before the tops began to bend over. After harvest (on June 30th) the bulbs were dried for 1 week in the shade (cured) and placed in dry storage at 0°, 15°, and 30°C. Periodic dissections of bulbs showed that, by the time the bulbs were placed in storage, leaf initiation had resumed. At 15°C. a new leaf was initiated about once every 2 weeks (half the rate observed in the field during growth) and at 0° and 30°C. such leaf initiation took place at about half the rate observed at 15°C. Young leaves, which had been formed in the field before harvest, began elongating after about 2 weeks of storage at 15°C.—some 3 to 4 weeks before they became visible above the bulb top. At 0° and 30°C. only slight sprout elongation was evident towards the end of the 10-week storage period. The leaf-elongation associated with sprouting appeared not to be related to differentiation of the much younger leaves at the shoot apex.

Abdalla also stored freshly harvested and cured bulbs at a series of temperatures—0°, 5°, 10°, 15°, 20°, 30°, and 40°C.—and removed them after 2, 4, 8, and 16 weeks, to flats of moist sphagnum held at 15°C. to observe sprouting and rooting. The level of rest, as indicated by the time required for half of the bulbs to produce visible sprouts after being placed in sphagnum, decreased at all storage temperatures, but most rapidly at the intermediate temperatures of 10° and 15°C., and least rapidly at 30° and 0°C. The control bulbs, placed in sphagnum without prior storage, sprouted after 40 days ('Excel') and 60 days ('Australian Brown 5'). Root emergence in response to the several storage temperatures followed the same pattern as sprout emergence, but the roots emerged much more quickly than the sprouts. As has long been known, root emergence is sensitive to the supply of available moisture. Freshly harvested bulbs of 'Australian Brown 5', 'Excel', 'Sweet Spanish', 'White Creole', and 'Yellow Bermuda', all rooted within 3 days at 15°C. if their stems were placed in contact with water. Similar bulbs placed in moist sphagnum required an additional 2 to 3 days to root. Abdalla concluded that sprouts show definite evidence of a rest period, and that, after harvest rest decreases at all storage temperatures, although more rapidly at some than at others. Little or no evidence was found of rest in roots. Root system vigour, however, as measured by the total weight of roots developed, is affected by storage temperature; the root systems developed on bulbs that had previously been stored at 15°C. were much heavier than the root systems developed on bulbs that had been stored at higher or lower temperatures.

Under conditions favourable for root emergence, bulbs always rooted before they sprouted. It seems possible that, where moisture is available through the root system (as in planted bulbs), early sprouting is favoured. Continuous removal of newly formed roots from planted bulbs delayed sprout emergence.

In summary, Abdalla's (1962) work suggests that, while there is a definite rest in the sprouts of onion bulbs, this rest is relatively brief. There is only a short period in the life of an onion plant when leaf initiation is not taking place, and even then the cells of the shoot apex show evidence of cell divisions (Abdalla, 1962). Sprouting, however, is not the result of leaf initiation during storage but of elongation of leaves present in the bulb at the time of harvest. Elongation of these leaves within the bulb may start several weeks before the sprout becomes visible at the bulb top, so that the beginning of sprout development is usually not observed. The concept of rest in the onion bulb is further complicated by the fact that rest disappears gradually—there is no easily measured 'rest period' which ends abruptly. It seems clear, for onion bulbs held in storage for long periods, that the bulbs soon become capable of rooting and sprouting, and are then held dormant by conditions of moisture or temperature which are unfavourable for growth.

RELATIVE HUMIDITY

Next to choice of cultivar, relative humidity probably has more influence on keeping quality of onion bulbs than any other factor. Some loss of moisture is essential during curing; but, after curing, moisture loss should be held to a minimum. In early-onion districts, where onions may be held for several weeks because of low prices, the loss of weight from moisture alone can be considerable. In the Imperial Valley of California, where at harvest time the temperatures are high and the relative humidities low, the loss in weight was determined for the hybrid 'White Alamo'[1]. Bulbs were harvested on April 6th and cured in baskets until May 6th, when 40 bulbs weighing 17·5 lb. were selected and stored in a hamper under an open shed. By June 10th, the weight loss was 5·7 per cent, by July 10th, it was 11·4 per cent, and by August 10th, it was 14·3 per cent. None of the bulbs had rotted or sprouted during this period. These data show that, under low humidity and high temperature conditions, bulbs continue to lose water, and at a relatively constant rate.

Wright *et al.* (1935) determined the losses in weight obtained with the

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[1] Unpublished data of H. A. Jones.

Yellow Globe-type of storage onion when bulbs were held at different temperatures and different relative humidities (Table XXII). As was to be expected, weight losses increased with an increase in temperature and a decrease in relative humidity.

TABLE XXII

CUMULATIVE LOSS IN WEIGHT OF YELLOW GLOBE-TYPE ONION BULBS DURING STORAGE, ARLINGTON, VIRGINIA

(Wright *et al.*, 1935)

Weighing date	Storage temperature (°F.)	Relative humidities of storage		
		65%	80%	90%
		Loss in weight		
		(%)	(%)	(%)
Oct. 18th	32	0·00	0·00	0·00
Nov. 22nd	32	1·16	0·99	0·23
Feb. 2nd	32	2·97	2·63	0·87
Mar. 23rd	32	4·97	4·39	2·93
Oct. 18th	40	0·00	0·00	0·00
Nov. 22nd	40	1·80	1·57	1·24
Feb. 2nd	40	4·35	4·13	2·96
Mar. 23rd	40	6·78	6·44	5·25
Oct. 18th	50	0·00	0·00	0·00
Nov. 22nd	50	2·13	1·53	1·16
Feb. 2nd	50	5·18	4·07	3·27
Mar. 23rd	50	8·23	7·00	5·94

High humidity in storage, especially when free water accumulates on the bulb, can be disastrous. In a saturated atmosphere diseases spread rapidly, and a rotting bulb may easily infect all of those surrounding it. Different relative humidities greatly influence the amount of root development but not the amount of sprouting. As onions are held in storage, root primordia develop at the base of the bulbs, eventually elongating or distorting the bases and causing the scales to break away, so giving the bulbs a shaggy appearance. The extent to which these primordia develop seems to differ with the cultivar. 'Sweet Spanish' is especially prone to become misshapen towards the end of the storage period. However, as long as the bulbs are kept dry, root primordia do not elongate. Such root formation is usually most common in onions that have been stored in closely-woven sacks, such as burlap, where ventilation is impeded and humidity increases within the sack. Bulbs that are stored in crates often root if trash in the crates prevents the free movement of air. It is not unusual to find the outer two or three layers of bulbs in excellent condition, but bulbs in the centre of the crate badly rotted and rooted because of excess moisture.

From the above review it is evident that relative humidity may have several distinct effects on stored onions. Humidity control is certainly more effective than temperature control in preventing the spread of rot-causing organisms and the elongation of roots. Water loss, on the other hand, takes place at all the temperatures and humidities that are commonly encountered in storage. It is difficult to evaluate the effect of storage conditions on water loss, because this loss varies with changes in humidity or temperature but cannot be estimated from either of these alone. Physiologists have simplified such comparisons by using *vapour pressure deficit*, a measurement dependent upon both temperature and the moisture content of the air. Anyone interested in comparing water loss from bulbs stored under different conditions can acquaint himself with this concept by referring to a textbook of plant physiology such as that of Curtis & Clark (1950).

STORAGE DISEASES AND DEFECTS

Attention is called here to Chapter XV, where descriptions of diseases and defects associated with storage—such as freezing injury and ammonia injury—may be found.

RESPIRATION IN STORED ONIONS

In stored onions, as in all living tissues, respiration results in the continual loss of stored food (dry matter) and in the production of heat. Although the respiration-rate of onion bulbs is much lower than that of most vegetable crops, the loss of dry matter can be important, because onions are often stored for long periods. This loss may be especially important in onions that are held for dehydration, as dry matter is the end product. The heat evolved in respiration must be removed either by ventilation or by refrigeration.

Rates of dry-matter loss and heat production can be estimated from data on respiration such as are given by Wright *et al.* (1954), Thornton (1933), and Appleman & Smith (1936). Dry-weight losses vary from 0·1 to 0·9 lb. per ton (0·907 tonne) of bulbs per 24 hours for 'Southport White Globe' onions stored at 0°C. and 'Yellow Bermuda' stored at 25°C., respectively. For 100 days of storage these losses would amount to about 0·5 and 4·5 per cent, respectively, of the total dry matter of the stored bulbs. These figures do not include weight-loss from other causes, such as transpiration, rots, or sprouting. For the same two lots of onions discussed above, heat production, which is proportional to the dry-matter loss, amounted to 660 and 5,900 British thermal units per ton (0·907 tonne) of bulbs per 24 hr. (1 B.T.U. = 252 calories). This heat must be removed from large bulk storages by ventilation, or from cold storages by refrigeration. The refrigeration required, however, is much less than for crops such as lettuce, broccoli, and spinach, which may respire 15 to 20 times as rapidly as do dry onions. While respiratory intensity can be expected to vary with temperature, cultivar, maturity, duration of storage, and presence of sprouts and roots, existing data do not permit specific conclusions on these points.

The respiratory rate of a given lot of onions depends upon the storage temperature. In 'Southport White Globe' onions held at nine temperatures between 0° and 40°C., the respiration-rate increased with increasing temperature over the entire range.[1] Between 0° and 35°C., respiration increased slightly over four times, but between 35° and 40°C., it doubled. However, there is evidence that storage at 40°C. was injurious to the bulbs, and injury could account for the high respiration-rate at that temperature. While increasing temperatures increase the rate of both dry-weight loss and heat production, the important observation is that the respiration-rate of onions rises more slowly as temperature increases than it does in most crops. This may contribute, in part, to the feasibility of high-temperature storage for onion bulbs.

SPROUT INHIBITORS

In recent years many growth substances have been used to prevent or delay sprouting in stored onions, potatoes, and other crops. Of the many chemicals tested, maleic hydrazide has been found to be the most effective in preventing sprouting and rooting of onion bulbs (Wittwer *et al.*, 1950; Paterson & Wittwer, 1953). Maleic hydrazide is beneficial not only on those cultivars that have a short storage life, but is also beneficial in extending the shelf-life of good storage types after they have been removed from prolonged cold storage. This chemical does not produce an undesirable flavour or off-colour in the bulb.

A single application of 2 or 3 lb. per acre is usually made to the field when the plants are nearly mature and the tops are beginning to fall. The tops must be green, to absorb the chemical for translocation into the bulb; but if the chemical is applied too early, the onion bulbs become hollow or puffy. Rain within 24 hours after an application may reduce its effectiveness. Bulbs that are to be used for seed production should not be treated. The directions for application which are furnished by the manufacturer should be followed, but the grower must determine that the chemical is used in compliance with the pure-food laws of his country.

STORAGE STRUCTURES

Storage structures vary from simple shelters that do no more than protect from rain and sun, to well-insulated houses with heaters to prevent freezing and cold-storage rooms that provide constant low temperatures.

In the Bombay region of India, special storage houses are built with grass-thatched roofs, and with sides made of bamboos that are suitably spaced to allow good air circulation.

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[1] Unpublished data, Department of Vegetable Crops, University of California, Davis.

In the early-onion growing districts of Japan, onions that are to be stored for some time are tied in bundles and hung on bamboo poles in well-ventilated shelters which protect them from sun and rain. In the Osaka Prefecture almost every onion grower has one or more of these huts (Pl. 35(*c*)). About 17,000 lb. of onions can be stored in a hut of 144 sq. ft. These onions keep well until October, when they go into cold storage.

In the Valencia district of Spain, the large onions which are harvested in July and August, if not shipped at once, are stored in long, narrow, inexpensive sheds. The onions are piled in bulk to a depth of 5 or 6 ft (Pl. 36(*a*)), and may be held so until the following March or April.

In the western United States, where the Spanish-type onion is produced, a portion of the crop is moved to market directly from the field, but most of it is stored for a time in crates or bags in well-ventilated and insulated houses. Crates, which are much to be preferred, are stacked on slatted floors in storage houses that are built so that air circulates from below the floor, upwards through the crates, and out through vents in the roof—or, alternatively, dry air is forced up through the crates, periodically, by fans. The temperature of the storage gradually becomes lower as winter approaches. An attempt is made to hold the onions at about 32°F. By January, most of the Spanish-type onions have been moved out of storage.

In the northern United States and in Canada, most of the Yellow Globe crop is stored in well-insulated and well-ventilated houses. Onions may be piled in bulk from 8 to 14 ft deep on slatted floors with air tunnels below, through which heated air can be forced up through the bulbs—first to help in the curing, and later to provide ventilation. In this same region a considerable quantity of onions is held in cold-storage warehouses that are located in the large terminal markets. Refrigeration keeps the temperature of these warehouses at about 32°F. throughout the storage period. Many onions are moved from common storage into cold storage with the advent of warm weather; others are placed in cold storage at the beginning of the storage season and moved out gradually into the marketing channels.

GRADES AND GRADING

In the United States of America, many onions are sold according to federal grades. The purpose of these grades is to establish a common basis, between buyer and seller, for judging the quality of the product in relation to its sales price. Transactions are based on certificates of grade, which are issued under federal or federal-state authority and are valid evidence in all federal courts and most state courts. This method is especially desirable when the buyers have no way of examining the product.

Grade standards have been established for many kinds of onions, such as Bermuda, Creole, northern grown onions, etc. For each grade, certain requirements must be met. As an example, *U.S. No. 1* northern onions must be of uniform varietal characteristics, mature, fairly firm, fairly well shaped, free from decay, from doubles, from bottlenecks, from scallions, and from damage caused by seed-stems, splits, tops, roots, sunscald, sunburn, sprouting, freezing, peeling, cracked fleshy scales, dirt or staining, foreign matter, disease, insects, or by mechanical or other means. Unless otherwise specified, the minimum size shall be 1·5 in. in diameter, and, in the case of yellow, brown, or red onions, 40 per cent or more, and in the case of white onions, 30 per cent or more, by weight, shall be 2 in. or larger in diameter. Certain tolerances are permitted for defects and for size. The meaning of such terms as 'mature', 'fairly firm', etc., is defined in publications. Different size-grades for northern onions have been established, e.g. *U.S. No. 1* Boilers must meet all requirements of *U.S. No. 1* except for size, which is between 1 and 1⅞ in. in diameter. *U.S. No. 1* Picklers must meet all requirements of *U.S. No. 1* except for size, which must not be more than 1 in. in diameter. Detailed specifications for all the different grades of onions can be obtained from the United States Department of Agriculture, Agricultural Marketing Service, Washington, D.C.

In the United States, most onions are graded in central packing sheds (Pl. 36(*b*)) and warehouses, which are usually located along railroad sidings, where the bagged onions can be loaded directly into refrigerator cars or trucks. Onions are run over power-operated mechanical graders that blow and screen out any dust and loose scales, and grade the onions into different sizes. As the bulbs move along the grading table, undesirable ones are removed. Usually the several size-grades are packed separately to make a more uniform and attractive product. Portable onion graders which allow cleaning, grading, and sacking in the field, are used in some areas (Pl. 37(*a*)).

TRANSPORTATION

Transportation of fruits and vegetables has been referred to as 'storage on wheels', implying that the environment during transport should simulate that acceptable for storage. Dry onions that are mature, well-cured, and free from disease and injuries, are well adapted to long-distance transportation; but the early crop, which is often immature when harvested, and not thoroughly cured, may be almost as difficult to transport as perishable leafy vegetables. The loss of from 3 to 5 per cent of weight during transport can seldom be avoided, as the bulbs must be kept dry and well ventilated.

Various kinds of containers are used for the transport of onions. In the United States, several types of wooden containers are employed, but most railroad and truck shipping is in 50-lb. paper or cotton open-mesh or burlap bags. Smaller open-mesh bags, which can be used for retail marketing, are also used.

The 50-lb. bags are usually loaded some 600 to 800 per railroad car. When properly loaded, the bottom bags rest on carefully placed excelsior or paper pads, to prevent bruising, and 6 or 7 layers of bags are placed on these in such a way as to prevent movement in the car and to allow air to circulate around each bag. Early onions, which do not keep well in storage, may be shipped under refrigeration, but the late crop is usually shipped in refrigerator cars without ice. In cold weather, ventilators may be manipulated to prevent freezing, or heaters may be used. In Middle and Upper Egypt, where most of the onions that are grown are for export, the bulbs are packed in large burlap bags. Some of the crop is hauled from the field to Alexandria and Port Said by truck, but most of it is moved by camels to railroad sidings. Here the bags are stacked until they can be hauled by rail to Mediterranean ports, where the onions are graded and resacked for shipment. Spain and Chile also export onions in considerable volume by ship. These are packed in wooden crates which provide for good ventilation and easy inspection.

XIII

ONION SEED PRODUCTION

THE production of onion seed has long been, and will continue to be, a highly-specialized industry. In the United States, especially, most of the onion seed is supplied by men who are skilled in the business of seed production. Years of experience are required to become conversant with many of the details, such as the best cultural practices, cultivar characteristics, rogueing, insect and disease control, pollination, harvesting, curing, thrashing, and milling.

Onion seed is produced throughout the temperate and subtropical countries of the world. Argentina, Australia, Canada, Cyprus, Egypt, England, France, Hungary, Israel, Italy, Japan, Mexico, the Netherlands, New Zealand, Spain, the Republic of South Africa, the United States, and the U.S.S.R., all have sizeable onion-seed industries. In countries where high temperatures prevail throughout the year, only the easy-bolting types of onions, requiring relatively little low-temperature exposure, can produce seed. In the United States, most seed of the long-day types is produced in south-west Idaho and eastern Oregon, although some is grown in the interior valleys of California and on the western slopes of the Rocky Mountains (in Colorado and elsewhere). Seed of the short-day types is produced in the Southwest, chiefly in the Imperial Valley of California. In Canada, over 90 per cent of the seed is grown in the interior of southern British Columbia.

CLIMATIC AND SOIL REQUIREMENTS

Temperature throughout the year and day-length during the growing-season set broad limits to the areas that are suitable for seed production. When the seed is produced from bulbs that have been raised during the preceding year, the length of the growing-season that is required for the crop is relatively short, and seed may be produced at fairly high latitudes or altitudes, e.g. in England and in the Netherlands. The long days early in the growing-season, which are characteristic of high latitudes, favour rapid bulbing rather than flowering; this limits the seed production of short-day cultivars to lower latitudes than those which are suitable for long-day types. A fairly cool temperature over a considerable time, usually while the bulbs are in storage or over-wintering in the field, conditions the plants for seed-stalk formation. Temperatures of between about 4·5° and 14·0°C. are favourable for this conditioning process, and the longer these temperatures prevail, the more flower-stems will each plant produce, and the more flowers will there be in each umbel—at least on the average. High temperatures early in the season, or at the time of year when the young scapes are forming, cause many plants to produce bulbs instead of flower-stems, and may reduce greatly the number of flowers per umbel (Chapter VIII, pp. 101–3).

The best seed-producing areas are those that have low atmospheric humidity. Long rainy periods or heavy dews and fogs favour the development of downy mildew, purple blotch, and other diseases. While the onions are in flower, clear, bright days are necessary to ensure insect activity for pollination. It is equally important to have hot, dry weather during the harvesting, curing, and thrashing of the seed.

The onion seed crop can be grown on a wide range of soil types, but light, sandy soils should be avoided. Heavier soils are preferable because they are cooler, have a higher water-retaining capacity, and are more productive.

Growing, Harvesting, and Storing Mother Bulbs

Mother bulbs are grown in about the same way as the crop for market (Chapter XI), except that the rate of seeding is usually higher—so that smaller bulbs are produced, as these keep better in storage. The bulbs are harvested after the tops begin to fall and while they are still green (Pl. 37(*b*)). The tops are removed and the bulbs dropped into crates or other containers. In dry climates, burlap bags are generally used (Pl. 37(*b*)), and these can be left standing in the field for several weeks until the bulbs are well cured. When bulbs mature under extremely high temperatures, they may be exposed to the hot sun, and precautions must then be taken to prevent sunburn. White cultivars, especially, should either be harvested or have the bulbs covered with soil shortly before the tops start to go down.

Mother bulbs are usually stored under conditions similar to those which are used for the market crop. If mother bulbs are to be planted in the spring, they are usually over-wintered in warehouses where the temperature can be controlled. As already noted, storage temperatures greatly influence the subsequent flowering of the plants (H. A. Jones & Emsweller, 1939; Woodbury, 1950; Atkin & Davis, 1954). Extremely high storage temperatures either delay or inhibit flower formation. Temperatures ranging from 4·5° to 14°C., with an optimum at about 11° to 12°C., are best for storage of mother bulbs which are to be planted in the late autumn or early spring. Proper storage temperatures not only stimulate the development of new leaf and root primordia, but condition the bulbs for flower and seed production. Plants developed from bulbs which have been stored at optimum temperatures usually flower earlier (Pl. 38(*a*)), mature their seed earlier, and produce a heavier yield of seed, than plants developed from bulbs which have been stored at higher or lower temperatures. Data showing the effects of storage temperatures on seed yield are given in Table XXIII.

TABLE XXIII

NUMBER OF SEED-HEADS PER PLOT, AND SEED YIELD PER ACRE, FROM MOTHER BULBS OF 'EBENEZER' THAT HAD BEEN STORED AT FIVE DIFFERENT TEMPERATURES. DATA FOR FIVE YEARS, DAVIS, CALIFORNIA

(H. A. Jones & Emsweller, 1939)

Storage temperature (°C.)	Seed-heads per plot (Ave. no.)	Yield of seed per acre					
		1927 (lb.)	1928 (lb.)	1929 (lb.)	1930 (lb.)	1931 (lb.)	Mean (lb.)
3·6	190	561	290	495	772	1,248	673
8·0	214	1,259	196	505	768	1,486	842
12·0	238	1,386	381	620	804	1,200	878
30·0	54	276	16	63	353	7	142
Warehouse	213	861	234	519	948	1,159	744
L.S.D.[1] at 5% level							70

[1] Least significant difference.

The above data show the variations in seed yields that can be expected from mother bulbs stored at different temperatures. These variations are not the same from year to year, however, as climatic conditions modify the effects of storage.

Poor-keeping cultivars that are to be held over the winter for spring planting, should be stored first at about 0°C. and then moved to higher temperatures for a few weeks during the latter part of the storage season.

Where onions are grown as a winter crop, mother bulbs are usually harvested in the spring, stored over the summer, and planted in the autumn. In the Imperial Valley of California, where temperatures of 100°F. or higher are reached on an average of 115 days during the summer, and where temperatures of 118°F. are not uncommon, protection from the hot sun and occasional rain is provided by storing the mother bulbs in hampers under covered sheds which have open sides. The hampers are stacked to give good aeration throughout the pile. When the hampers are being filled, an insecticide is dusted on the bulbs to keep insects under control throughout the storage period (Pl. 38(*b*)). 'Excel' and 'Texas Early Grano' can be stored in this manner from April until planting time in October. As small and medium-sized bulbs keep better than large ones, the production of large bulbs should be avoided by thick planting or by curtailing either water, fertilizer, or both.

ISOLATION

The location of onion seed fields should be planned well in advance of planting, so that adequate isolation can be obtained. Complete isolation is practically impossible, as pollination is entirely by insects which are able to carry pollen from field to field over long distances. The greater the distance between onion fields, however, the less will be the amount of crossing. About one-quarter of a mile between cultivars gives fair isolation, but plantings for commercial seed production should be farther apart when possible. Cultivars of different colour should be planted at least three miles apart. In districts where seed growing is concentrated, certain localities should be used for cultivars of similar colour, shape, and growth characteristics.

When crosses occur between red and yellow onions, the bulbs that are heterozygous for red can easily be detected in the yellow progeny, but the yellow colour is masked in the red cultivar. Although the red colour is diluted somewhat in the cross, it is almost impossible to separate the heterozygous reds from the homozygous reds. When red or yellow cultivars are crossed with white onions carrying the colour inhibitor *I* (dominant white), the hybrid bulbs are whitish or buff-coloured. These are difficult to detect in the white cultivars, because disease organisms and soil-stain often cause a similar buff coloration. The dominant white out-crosses can, however, be detected in coloured cultivars. Certain white onions, the so-called recessive whites, when crossed with red or yellow onions, produce red or yellow hybrids. The recessive and dominant whites can be differentiated by a simple chemical test (E. W. Davis, 1954). When the outer fleshy scales of a white onion are treated with strong ammonia fumes, the scales of recessive whites remain colourless, but those of dominant whites will turn yellow. The reaction can be hastened if the outer scale is cross-hatched with a sharp knife. Understanding the inheritance of bulb colour will help in planning the location of seed fields in order to get the minimum amount of colour contamination (Chapter VI).

All of the common cultivars of *A. cepa* cross readily among themselves—except the 'tree' or 'top' onion (Proliferum group), which produces both bulbils and flowers in the umbel but no viable pollen. When *A. cepa* and *A. fistulosum* are planted in adjacent fields, some crossing occurs, but hybridization takes place more frequently in *A. fistulosum* than in *A. cepa*. The hybrids can easily be recognized among the progeny by their vigour and foliage characteristics. The above species do not cross with either the leek or the garlic. Hybrids between leek and onion have never been reported, although many attempts have been made to cross these two species under controlled conditions. Great-headed garlic, a relative of the leek, flowers rather profusely, but most of the flowers fail to produce viable pollen, so there is probably no danger of crossing.

PLANTING MOTHER BULBS

In warm climates, onion bulbs for seed production are usually planted in the autumn, regardless of the cultivar, while in cold climates certain cultivars are often planted in the autumn and others in the spring. Those which are planted in the autumn should be set sufficiently early to become well rooted before the advent of extremely cold weather, as well-rooted bulbs are injured less by freezing than bulbs that lie dormant in the soil.

In preparation for planting, the land is usually ploughed, disked, and harrowed, and furrows are made about 3 to 3½ ft apart and 4 to 6 in. deep, to receive the bulbs. The furrows can be made and the bulbs dropped in one operation, or these operations may be performed separately. For large acreages, bulbs are usually dropped into the open furrow through chutes from the rear of a truck or wagon, or from large hoppers built on wheels (Pl. 39(*a*)). One or two rows may be dropped at a time; the bulbs are set upright later on, and covered with soil.

The size of mother bulbs used varies somewhat with the grower, the district, and the cultivar; in general, the best practice is to use medium-sized bulbs and to plant rather closely. Usually, some 6,000 to 8,000 lb. of bulbs are planted per acre, but the amount planted may be much greater than this. To obtain information on seed yield from different-sized mother bulbs, H. A. Jones & Emsweller (1939) conducted experiments at Davis, California, over a 4-year period with 'Yellow Globe Danvers'. Eight different sizes of bulbs were used; these were planted in rows 3 ft apart, with the bulbs in the row spaced 8 in. from centre to centre. The results are given in Table XXIV.

Each increase in size of bulb was accompanied by an increase in the

TABLE XXIV

YIELD OF SEED-HEADS AND SEED FROM MOTHER BULBS OF DIFFERENT SIZES. AVERAGE OF FOUR YEARS, DAVIS, CALIFORNIA

(H. A. Jones & Emsweller, 1939)

Weight of mother bulbs (gm.)	Seed-heads per plant (no.)	Seed per acre (lb.)	Seed per plant (gm.)
11–20	2·41	407	9·16
21–30	3·02	551	11·98
31–40	3·46	648	13·98
41–50	3·74	668	14·65
51–60	4·14	744	16·08
61–70	4·42	759	16·50
71–80	4·64	786	17·13
81 and over	4·75	796	17·30
L.S.D.[1] at 5% level	0·14	40	0·84

[1] Least significant difference.

Photo W. A. Ward

(*a*) Removing the roots and tops of onions shortly after harvest. The bulbs are thrown into windrows to dry Upper Egypt

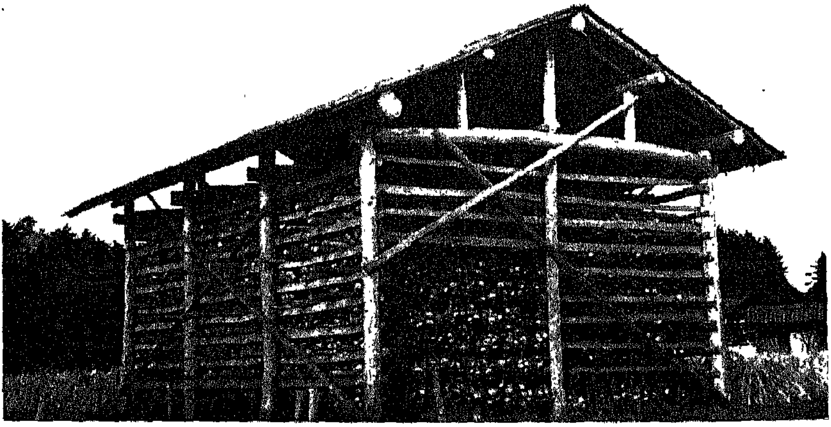
Photo S. Abe

(*b*) Removing the tops and roots of early onions in Japan, in preparation for the market.

PLATE 34

(*a*) Packaging early onions in Japan. As the price of early onions is usually low, they are packed in inexpensive straw baskets.

(*b*) Harvesting storage-type onions in Osaka Prefecture, Japan. The onions are tied in bundles before being taken to the huts in the background for curing.



Photos S. Abe

(*c*) An onion storage hut in Osaka Prefecture, Japan. Bundles of onions are hung on bamboo poles to cure.

PLATE 35

Photo E. W. Davis

(*a*) Storing 'Grano' onions in the Valencia district of Spain. The onions may be held in storage from August until the following March or early April.

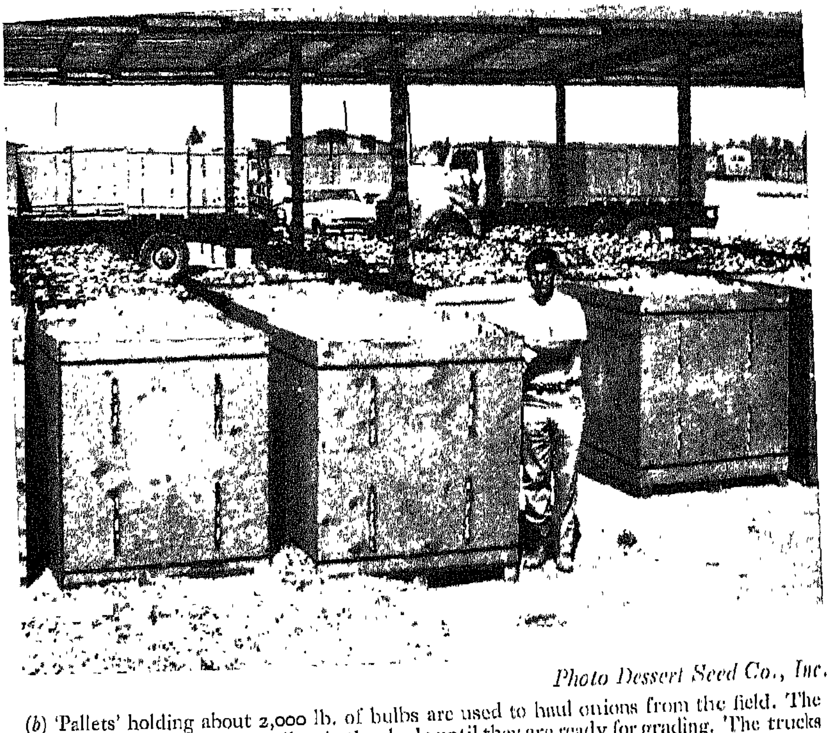
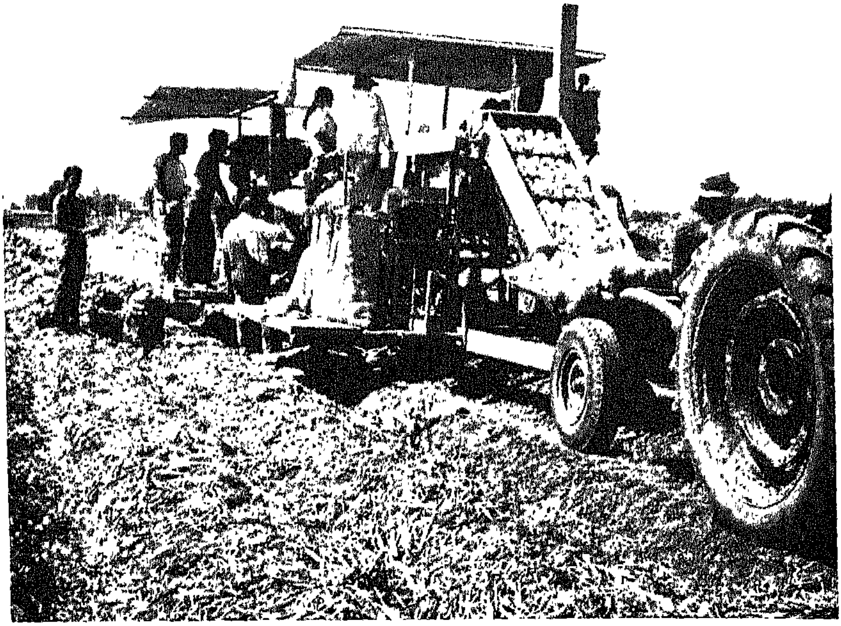


Photo Dessert Seed Co., Inc.

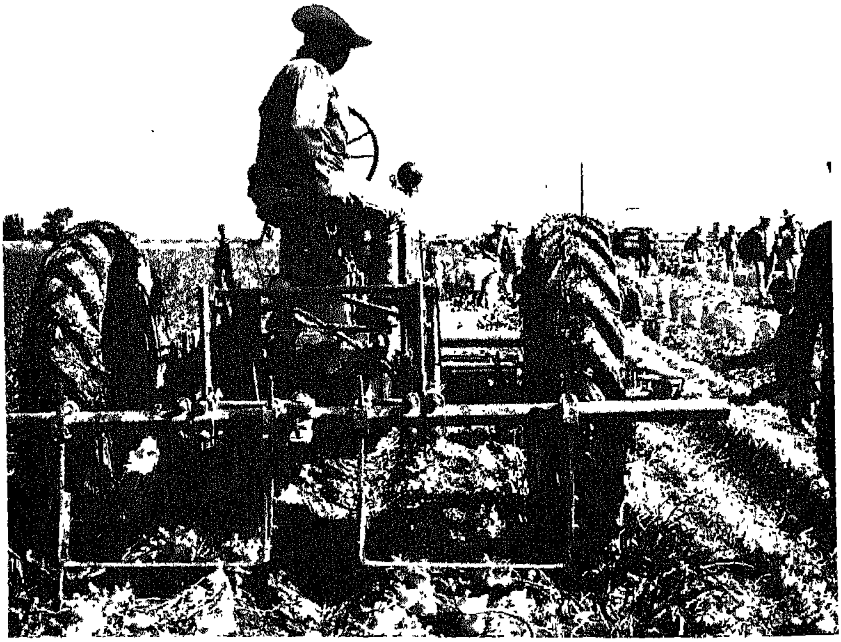
(*b*) 'Pallets' holding about 2,000 lb. of bulbs are used to haul onions from the field. The bulbs are then stored in the pallets in the shade until they are ready for grading. The trucks in the rear are loaded with pallets which are handled entirely by booster machines.

PLATE 36



(*a*) A portable onion grader at work. As the grader moves slowly through the field, cull onions are removed, bulbs are graded for size, and bags are filled and sewed. Imperial Valley, California.

Photos Dessert Seed Co., Inc.



(*b*) Harvesting mother bulbs to be used for the seed crop. The knives attached to the rear of the tractor are run beneath the rows of bulbs, to cut the roots and loosen the soil before the bulbs are picked up and put into burlap sacks. The bulbs shown here have been topped. Imperial Valley, California.

PLATE 37

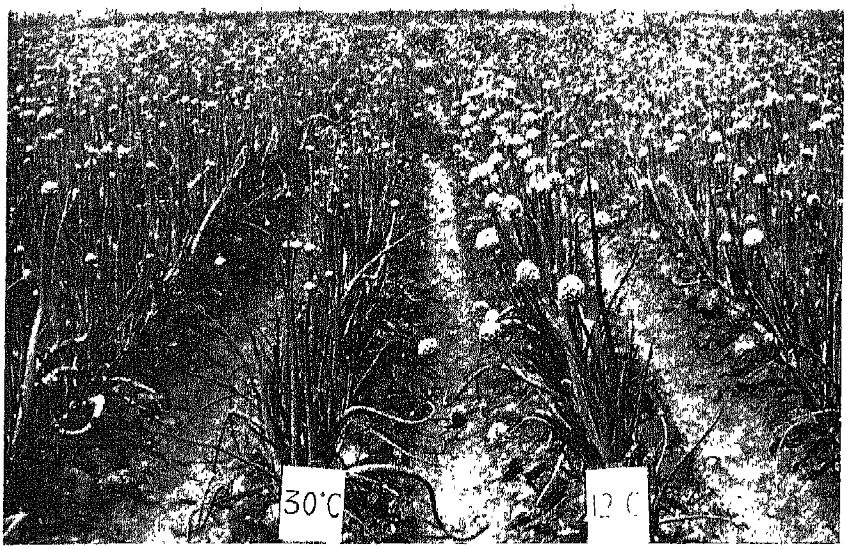


Photo Calif. Agric. Exp. Sta.

(*a*) Seed plants of 'Yellow Globe Danvers' growing at Davis, California. On the left are plants from mother bulbs which were stored at 30°C.; on the right, plants from bulbs which were stored at 12°C Note the earlier flowering of those from bulbs stored at 12°C. (H. A. Jones & Emsweller, 1939).

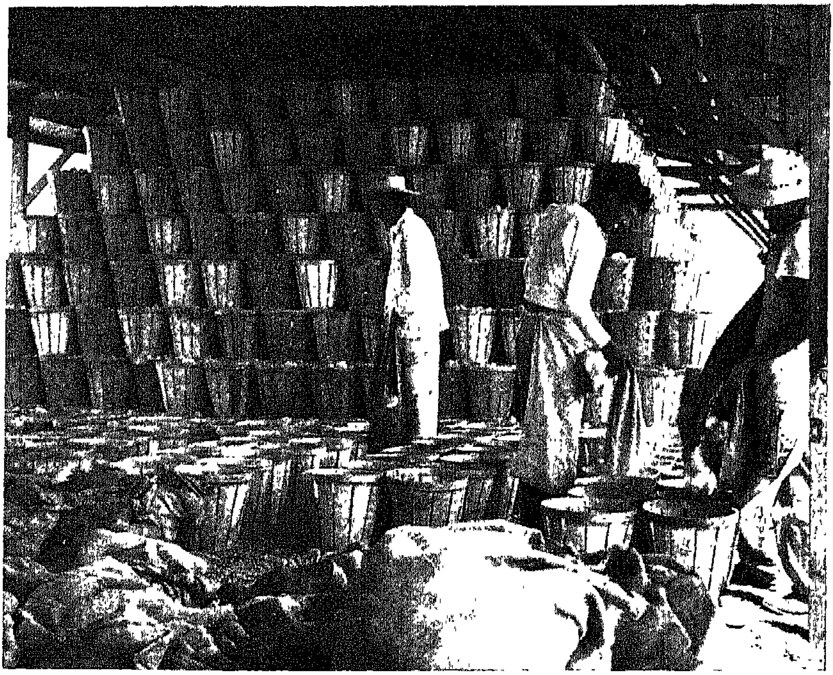


Photo Dessert Seed Co., Inc.

(*b*) In the Imperial Valley of California, seed-crop mother bulbs to be stored over the summer are placed in hampers, dusted with an insecticide, and stacked under an open shed for good ventilation.

PLATE 38

(a) Dropping male-sterile mother bulbs for the production of the hybrid Granex. The bulbs are dropped by machine, two rows at a time, and then set upright by hand. Rows of bulbs of the pollen parent (centre bed) were planted and covered earlier. The rows are about 3½ ft apart. Imperial Valley, California

Photos Dessert Seed Co., Inc.

(b) Harvesting seed of the hybrid 'Granex' in the Imperial Valley of California. Men precede the cutters to separate the seed-stalks of male rows (edge of picture) and female rows (centre four), to avoid contamination. The hybrid seed on the female plants, being the most valuable, is cut first. All harvesting is done by hand.

PLATE 39

Photo Crookham Co

(*a*) Harvesting hybrid onion seed in southwestern Idaho The seed-heads are dropped into burlap bags which are carried by the cutters The pollen rows were destroyed before harvest began

Photo U S Dep Agric

(*b*) Drying onion seed-heads in burlap bags in a drying yard at Olathe, Colorado The bags are shaken occasionally to obtain uniform drying

PLATE 40

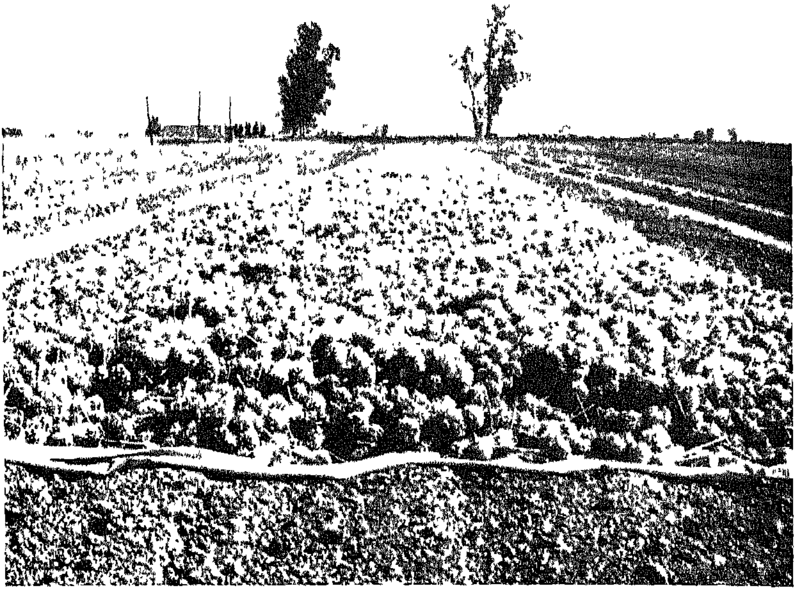


Photo Desert Seed Co , Inc

(*a*) Onion seed-heads drying on canvas in the Imperial Valley of California In this hot, dry climate the seed-heads are piled 8 to 10 in deep and are stirred several times to promote uniform drying

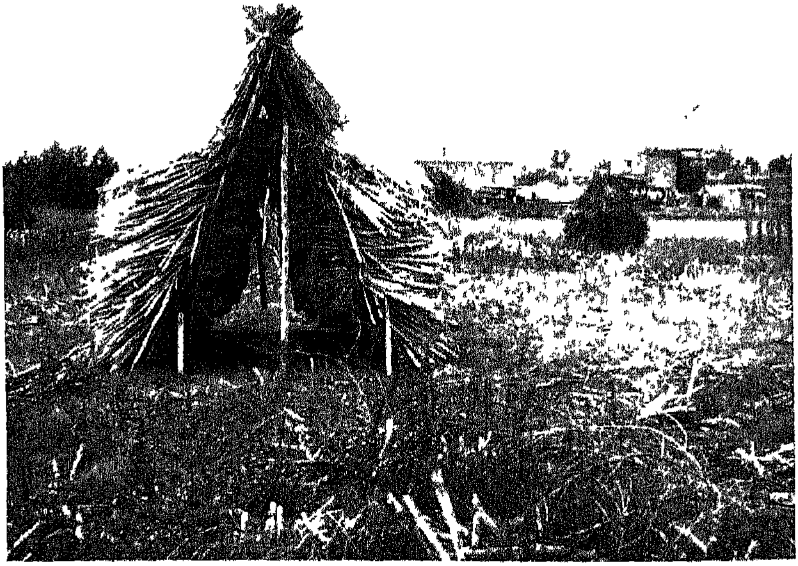


Photo E. W. Davis

(*b*) Drying onion seed-heads on frames in Voorburg in the Netherlands With their long seed-stems left attached, the seed-heads are arranged towards the centre of the stack, to protect them from rain.

PLATE 41

number of seed-heads per plant, in the seed yield per plant, and in the seed yield per acre. The greatest contrast in performance was between the smallest and next-larger size, and, in general, differences became less with each increase in size of the mother bulb. The main objection to small bulbs is that they often do not express the true shape characteristics of the cultivar, making it difficult to rogue for type.

Close spacing of mother bulbs seems to be one of the best means of increasing seed yield per acre. Spacing studies with 'Yellow Globe Danvers' were conducted for 3 years at Davis, California (H. A. Jones & Emsweller, 1939). Bulbs of medium size were spaced at 3, 4, 6, 8, and 12 in., in rows 3 ft apart. The seed yields were 1,337, 1,145, 884, 736, and 563 lb. per acre, respectively. Thus spacing has a tremendous influence on seed yield per acre. Each increase in spacing between plants gave an increase in the number of seed-stems per plant and in the seed yield per plant, but these increases were not sufficient to compensate for the reduced number of bulbs planted. Too-close crowding, however, has its disadvantages: ventilation around the plants is impeded, drying after irrigations is slow, and heavy dews and rains make the plants more subject to attack by downy mildew, neck-rot, and other diseases. It would seem best to space the plants sufficiently far apart in the row to provide good ventilation and give them room to 'forage', and to maintain a high population by planting the rows closer together.

An experiment in row spacing of mother bulbs was conducted by Vincent (1960) at Pullman, in the Palouse region of eastern Washington State, where the annual rainfall is 18 to 22 in., most of it coming in late autumn, winter, and early spring; the summers are usually dry. 'Yellow Globe Danvers' bulbs, mostly 2 to 3 in. in diameter, were planted in early April. They were set the diameter of the bulbs apart in the rows, which were spaced 6, 9, 18, and 36 in. apart. In 1951 the crop was grown without supplementary irrigation; in 1952, however, water was added when this was deemed necessary. The results of the experiment are given in Table XXV.

Seed yield per acre decreased with each increase in row spacing. Yields at the closer spacings, which are much higher than those generally obtained in commercial seed production, show at least one way in which seed yields per acre can be increased; but mechanical tillage at these spacings would be difficult, if not impossible. The higher seed yields in 1952 may have resulted from supplementary irrigations.

Seed yields vary with the cultivar, season, soil type, location, and production methods, but in general they are rather low when compared with yields which are known to be possible when all factors are favourable. Hawthorn & Pollard (1954) state that, for most cultivars, a yield of 400 to 500 lb. per acre is considered average. Yields much lower than these are often obtained; but on the other hand, under very favourable conditions, the yields may go as high as 2,000 lb. or more per acre.

TABLE XXV

EFFECT OF SPACING BETWEEN ROWS ON SEED YIELD FROM BULBS OF 'YELLOW GLOBE DANVERS'. TWO YEARS' TESTS, PULLMAN, WASHINGTON

(Vincent, 1960)

Year	Distance between rows			
	6 in.	9 in.	18 in.	36 in.
	Yield of seed per acre			
	(lb.)	(lb.)	(lb.)	(lb)
1951 (Without irrigation)	2,484	1,634	1,118	649
1952 (With irrigation)	5,451	2,972	2,296	1,758

Considerable effort has been made to improve the bulb crop, but there has not been a comparable effort to improve seed production. Breeders can contribute to this effort by developing cultivars that are resistant to diseases such as downy mildew, purple blotch, pink-root, fusarium, neck-rot, and yellow dwarf; by eliminating genes that cause female-sterility and undesirable male-sterility, flower abortion, and other abnormalities of the reproductive organs; by obtaining resistance to the injury caused by high temperatures during pollination and seed development; and by developing resistance to lodging and seed shattering. Critical studies are needed on cultural practices, and on the effect of nutrients and the time and method of their application. Cultivars differ in the storage temperatures and the duration of storage needed to condition them for seed production. Attention to these problems should pay dividends in increased seed yields and in better seed quality.

Seed production costs may sometimes be reduced by growing two or more crops of seed from one planting of bulbs. In the United States, 'Ebenezer' and Yellow-Globe types are occasionally handled in this manner. If a worthwhile second crop is to be produced, a good stand of healthy bulbs must remain in the field after the first seed crop has been harvested. Occasionally there are plants that do not bolt in the first year but form a cluster of bulbs which will produce seed in the second year. Most cultivars develop lateral branches at the base of the first year's seed-stem, which, if they form small bulbs, will usually bolt the following year. After the seed-heads of the first crop are harvested, the stalks are mowed and, when dry, are raked and burned. Under semi-arid conditions, the land is usually cultivated to destroy weeds and to throw a ridge of soil over the bulbs. The bulbs will then remain dry and dormant until autumn rain or a late irrigation starts them into growth.

Occasionally in the United States, bulbs produced in the south as a winter crop and harvested early in the spring are planted in the north in an attempt to grow a seed crop in the same year. Except for the easy-bolting types, this procedure usually results in failure. All cultivars have a short rest period before growth resumes, and although there is much variation, most short-day types do not start vigorous growth until about three months after harvest. Also, bulbs which are harvested early in the south usually have not received the long exposure to moderately low temperatures which is necessary for seed-stalk initiation. By the time the bulbs have completed their rest, and growth begins, the leaves are exposed to long days and the temperatures are high, so that bulb formation rather than flowering is favoured. If these late-planted bulbs are small, they will produce only larger bulbs; if they are large, they will divide and produce a cluster of smaller bulbs.

THE SEED-TO-SEED METHOD OF SEED PRODUCTION

A considerable amount of onion seed is produced by the seed-to-seed method, which avoids the use of mother bulbs. This method usually produces good yields of seed and eliminates the cost of raising and storing mother bulbs. Only stock seed should be used, and this should be planted at the appropriate time (with respect to the local climate) to ensure practically 100 per cent bolting of the plants. If only some of the plants bolt, the seeds that are harvested will include those from all the easy-bolting individuals, and this selection for easy-bolting types, at least for certain cultivars, may be disastrous to later commercial bulb production, where bolters are not wanted. Seed fields should be rogued to eliminate off-type plants, and these should be completely destroyed, so that there will be no danger of pollen production and subsequent contamination. Seed from the seed-to-seed crop should not be used again for seed production. Despite its advantages, it is almost impossible to do a completely satisfactory job of rogueing in seed-to-seed plantings.

Much of the onion seed from the Imperial Valley of California is produced by the seed-to-seed method. The seed is usually planted in dry soil and first irrigated between September 15th and 20th. Seeding must be sufficiently thick for the young plants soon to shade the soil. As large a plant as possible should be over-wintered, and cultural practices that provide a cool soil temperature should be employed. Plants will shade the soil best if the rows run north and south. Heavy, moisture-retaining soils are selected, as they are cooler than sandy soils. Most of the cultivars produced by the seed-to-seed method in the Imperial Valley are of short-day types, but seed of Sweet Spanish types is also produced there successfully.

In some northern districts of the United States, such as eastern Oregon and southwestern Idaho, considerable quantities of seed of long-day onions, such as 'White Lisbon' and 'Ebenezer', are produced by the seed-to-seed method. Seed is planted as early as June 15th—to obtain a large plant, with as little bulb formation as possible, for over-wintering. Where such early planting is necessary, the land must be occupied for nearly two crop seasons—a difficulty that is not encountered in warmer climates, where the crop is seeded in September.

FERTILIZERS

Fertilizer practices for the onion seed-crop vary widely, and there are very few experimental data to provide guidance. Most growers, however, attempt to maintain a high level of fertility. In the Imperial Valley the soil is rich in potassium, so that this element is never applied in the fertilizer, but both phosphorus and nitrogen are applied extensively. Whether the belief is valid or not, most growers feel that abundant phosphorus must be available to get good bolting and good-quality seed. Usually, 125 to 150 lb. of P_2O_5 per acre are applied broadcast, or are drilled into the surface soil before the beds are formed. The seed-to-seed crop must be well fed to get a large plant for over-wintering, so phosphorus and nitrogen are applied generously during the autumn, withheld for a time during the winter, and applied again after the flower primordia have differentiated in late winter or early spring.

Stuart & Griffin (1946), working in a glasshouse at Beltsville, Maryland, planted seed of 'Yellow Bermuda 986' on September 1st in burned shale in pots. The seedlings were transplanted to quartz sand on November 17th, and on January 4th the complete nutrient solution on which they had been raised was replaced by differential treatments, including a 'nitrogen' series with no nitrogen, and with low (2·76 parts per million N), medium (14 p.p.m.), and high (70 p.p.m.) nitrogen. The plants which were given little or no nitrogen were small and seldom divided to form more than one seed-stalk, but they bolted uniformly. Plants on high nitrogen were strongly vegetative and frequently bulbed instead of bolting. However, where seed-stalks were produced, the yield of seed per plant increased as the nitrogen in the nutrient solution increased. Stuart & Griffin suggest that maximum seed yields might be produced under a changing nitrogen supply: ample nitrogen during early growth, followed by restricted nitrogen until the seed-stalks are differentiated, and, finally, high nitrogen levels during seed development.

Fertilizer tests in the Willamette Valley of western Oregon, on autumn-planted 'Southport White Globe' bulbs, showed that spring applications of nitrogen gave significant increases in seed yield, whereas autumn applications did not (Schudel, 1952). The average yields with application of 0, 75, 150, and 225 lb. of nitrogen per acre, in combination with phosphorus and potassium, were 427, 596, 520, and 403 lb. of seed per acre, respectively, the optimum amount of nitrogen being 75 lb. Phosphorus, when used alone either in spring or autumn, had no significant effect on seed yields, but when used in combination with nitrogen, tended to increase seed yields as the amounts applied were increased. Potassium had no beneficial effects.

IRRIGATION

As most onion seed is produced in regions of deficient rainfall, irrigation is usually necessary for maximum yields. The crop grown seed-to-seed is usually planted in dry soil and irrigated. On saline soils, water may need to be held in the furrows for 2 or 3 days to move the salt away from the germinating seed and to the salt ridge between the rows (*see* p. 128). During extremely hot weather, several irrigations may be needed to help the seedlings through the soil. The frequency of later irrigation depends chiefly upon weather conditions and soil type.

MacGillivray (1948) conducted irrigation experiments at Davis, California, to determine the effects on seed yield. The summers at Davis are dry; most of the rainfall is between October and May. During the first and second years' tests, the precipitation was 15·5 and 15·4 in., respectively. Bulbs of 'Yellow Sweet Spanish' were planted in November the first year and in December the second year. Treatments were as follows: A, no irrigation; B, more water was added than was believed necessary to give maximum yields of seed; C, sufficient water was added to give near-maximum yields. The seed yields from the A, B, and C treatments were 467, 629, and 560 lb. the first year and 387, 698, and 471 lb. the second year, respectively. In both years the B plots gave the highest seed-yields, and there were no significant differences in seed germination among treatments. In the unirrigated plots there was a gradual removal of available water by the crop from the top-soil to a depth of 4 ft. By August 14th, only about 0·6 in. of available water remained in the upper 4 ft of soil. This is of interest because of the general belief that the onion is a shallow feeder.

Experiments in Utah by Hawthorn (1951) showed that a high level of soil moisture gave consistently high seed yields, especially in plantings with the rows spaced less than 30 in. apart. The data indicate that, for every inch which the rows were moved closer together between 36 and 9 in., the yield of recleaned seed increased approximately 33, 34, and 23 lb. per acre for the high, medium, and low soil-moisture treatments, respectively.

Regardless of the method of seed production, it seems that a good supply of moisture is needed. Saturating the surface soil and keeping it wet, however, should be avoided, as this facilitates the development of neck-rot and other diseases, and causes the seed-stalks to die prematurely.

HARVESTING AND CURING

Although all seed-heads do not mature simultaneously, there is usually only one cutting. This should be made sufficiently early to avoid too much loss from shattering of the seed, but, on the other hand, sufficiently late to obtain well-ripened seed. The seed-heads are cut with 4 to 6 in. of stem attached, an open hand being placed beneath the head, so that loose seeds will fall into the palm of the hand and not be lost. The seed-heads are dropped into canvas or burlap bags which are attached to the pickers (Pls. 39(*b*), 40(*a*)). When the picking bags are full, they are emptied into larger bags, which are loaded into trucks and hauled from the field; or the picking bags are emptied directly into trucks that have the sides and bottom covered with canvas.

In dry climates, most onion seed is cured by spreading the seed-heads loosely to a depth of about 6 in. on canvas sheets spread on the ground. In hot climates it is better to have the heads piled 8 to 10 in. deep to protect the seed from the sun (Pl. 41(*a*)). The seed-heads should be stirred occasionally to prevent moulding, and to obtain uniform drying. In some districts the seed-heads are dried in burlap bags which are placed on racks in drying yards, where they are shaken occasionally to facilitate drying (Pl. 40(*b*)). In the Netherlands, the heads are cut with long stems still attached, and then stacked in a sloping position with space for ventilation, and with the seed-heads towards the centre—to protect them from rain (Pl. 41(*b*)). Onion heads are also dried in shallow, stacked trays. In humid climates, seed-heads may be dried in glass-houses or other structures that give protection from rain, or they may be dried artificially by blowing heated air through them. After initial drying at low temperatures, the air blast can be raised to 110° to 115°F. without damaging the seed (*see* below under Seed Storage).

THRASHING AND MILLING

Seed is ready to thrash when the capsules and small seed-stems are brittle and break readily when rolled in the palm of the hand. Most thrashing is done with a combine (Pl. 42(*a*)). Precautions must be taken not to injure the seed, which should be examined occasionally, with a hand lens, for possible thrasher injury. The tailings may be re-run to recover seed that was missed in the first thrashing. As the seed is thrashed, it is gathered in bags, into each of which a tag is dropped before tying, and to each of which is attached another tag bearing the cultivar name and lot number. Small quantities of seed may be thrashed by rolling, flailing, stamping, or rubbing out between boards faced with finely corrugated rubber matting.

From the thrasher, the seed is taken to the mill—for cleaning to eliminate weed seeds, light seeds, and chaff. Most seedsmen do not wash onion seed until after milling, and then only the light fraction is washed. Seed should not be allowed to remain in the water for more than 2 or 3 minutes, and then should be drained and dried as rapidly as possible—on a screen or spread thinly on canvas. Surplus water is often removed by a centrifuge, before the final drying. Onion seed should be thoroughly dry before bagging, as moist seed soon starts to heat and mould, and quickly loses its capacity to germinate. Beginners often make the mistake of bagging the seed while it is still too moist (*see* next section).

SEED STORAGE

The maintenance of high viability in fresh, properly-harvested onion seed, depends almost wholly upon the control of two factors—*moisture content* of the seed and storage *temperature*. Both low moisture content and low storage temperature favour long seed life. Onion seed quickly deteriorates in hot, humid climates, often losing its viability in less than a year. It is usually much longer-lived than this in regions of low relative humidity. That the life of onion seed may be strikingly lengthened by proper storage conditions is illustrated by an experiment of Brown (1939), who dried 'Bermuda' onion seed to 6·4 per cent moisture and stored it in sealed containers for 13 years without evident loss in its ability to germinate.

The Asgrow Research Department (Anon., 1954) showed that, if the moisture content of onion seed was reduced to 6·3 per cent or lower and the seed was then hermetically sealed in cans, the original viability could be maintained for at least 3 years, even when storage was at temperatures as high as 90°F. They likewise showed that seed which was stored at room temperature in a desiccator over calcium chloride reached a moisture content of 1·2 per cent and retained its viability without serious loss for 9 years. Newhall & Hoff (1960) stored seed of 'Brigham Yellow Globe', with an initial germination of 99 per cent, in a desiccator over calcium chloride at room temperature. After 22 years, 75 per cent of the seed germinated; the plants from this seed were normal, although the bulbs were slightly smaller than those obtained from fresh seed of the same cultivar. Desiccator storage is excellent for small lots of valuable breeding material.

Lowering storage temperature likewise increases seed life. E. H. Toole *et al.* (1948) stored onion seed at 80 per cent relative humidity at 50°, 70°, and 80°F. The first highly-significant losses in germination were noticed after 24 weeks at 50°F., after 6 weeks at 70°F., and after 3 weeks at 80°F. Thus the life of onion seed may be prolonged by storage at low temperatures as well as by maintaining low moisture contents. These two storage factors may replace each other to a large extent, i.e. long seed-life may be attained by keeping the seed either very dry or very cold, but low moisture content is usually the easier of the two to achieve and maintain in commercial practice. An additional disadvantage of low-temperature storage is that, unless special precautions are taken, such low-temperature storage rooms become damp, and seed removed from them to room temperatures without drying may deteriorate rapidly.

The moisture content of seeds varies with the relative humidity of the air to which they are exposed, the actual equilibrium figures varying, however, with different crops. When onion seed is moved from one relative humidity to another, it either loses or takes up moisture, but in time it reaches an equilibrium with the surrounding atmosphere. E. H. Toole (1942), Barton (1943), and Harrington (1959) have all determined the moisture content of onion seeds stored at various humidities, and their results are in general agreement (Table XXVI).

TABLE XXVI

MOISTURE CONTENT OF ONION SEED STORED AT DIFFERENT RELATIVE HUMIDITIES. DATA FROM THREE AUTHORS AS INDICATED

E. H. Toole (1942)		Barton (1943)		Harrington (1959)	
Relative humidity of storage chamber (%)	Moisture content of seed (%)	Relative humidity of storage chamber (%)	Moisture content of seed (%)	Relative humidity of storage chamber (%)	Moisture content of seed (%)
—	—	—	—	10	4·6
—	—	—	—	20	6·8
—	—	35	8·6	30	8·0
45	9·0	—	—	45	9·5
65	11·0	55	11·4	60	11·2
73	12·0	76	14·9	75	13·4
80	13·5	—	—	—	—

Boswell *et al.* (1940) give further data on these relations. These equilibria between air relative humidity and seed moisture are almost completely independent of temperature. However, if seed is being dried by an air stream of low humidity, the *rate* at which the seed loses moisture increases with increasing air temperature. This, and the fact that heating air is one of the simplest ways of reducing its humidity, accounts for the use of heated air in seed drying. Seed that is quite moist may be injured by high air temperatures; drier seed is less subject to injury. Boswell *et al.* dried onion seed for 30 minutes in air at 150°F. without reducing its capacity for immediate germination, but there is evidence that such high temperatures may reduce seedling vigour. Until we have additional information, it appears safe to recommend drying onion seed at 90°F. until the moisture content is below 18 per cent, then at 100°F. until the moisture content is below 10 per cent, and finally at 110°F. to full dryness.

As moisture is withdrawn from seeds, it becomes increasingly difficult to remove the water which remains; to attain very low moisture contents, the drying air may need to be dehumidified as well as heated. The extent to which seed should be dried is mostly a matter of economics, depending largely on how the seed is to be handled after drying, and how long it is to be stored before use. Seed which is to be shipped to or through hot, moist tropical regions is now commonly dried to very low levels and sealed in metal cans. Such seed respires so slowly that the availability of oxygen in the can appears to be of little importance. For long periods of storage, such materials as polyethylene can only be considered moisture-resistant, not moisture-proof, although containers of metal foil plus polyethylene, if handled carefully, are nearly moisture-proof. For bulk storage, many seed companies have installed dehumidifying equipment to lower the relative humidity of seed storage rooms, and others attempt to control both temperature and humidity.[1]

PRODUCTION OF HYBRID ONION SEED

The production of hybrid onion seed is still a young industry and, like most young industries, has many unsolved problems. Seed producers are looking for ways to increase seed yields by both breeding and cultural methods. Much work is still to be done, but practices are sufficiently stabilized for tentative procedures to be suggested.

Mother bulbs of the seed-producing or female (A) and pollen-producing or male (C) lines are grown in about the same way as mother bulbs of the standard cultivars. To avoid mixing the A and C lines, it is wise to keep the field plantings well separated, to put bulbs in differently coloured bags, to use differently coloured labels at harvest, and to store separately.

The planting of the bulbs and the care of the crop for commercial production of hybrid seed also follow practices which are similar to those employed for the standard cultivars. The A and C lines are planted alternately in the field. The ratio of female to male rows may vary somewhat with different hybrids, but it is usual to plant 4 female rows to 1 male row in an 8 to 2 or 4 to 1 arrangement (Pls. 39(*a*), 40(*a*), 42(*b*)).

To get the maximum amount of high-quality seed, the flowering periods of the A and C lines must coincide as closely as possible. An abundance of pollen should be available for those flowers which open early in the A line as well as for those which open late. Thus, an ideal C line starts to flower a few days ahead of the A line, and continues to flower and produce an abundance of pollen as long as the A line is in bloom. If this does not occur naturally, it can often be achieved by adjusting planting dates. In the Imperial Valley of California, where most of the seed of the short-day hybrid 'Granex' is grown, the bulbs of the C line are planted about 4 weeks ahead of those of the A line. In another method which is used extensively to synchronize flowering in this hybrid, the C line is grown from bulbs and the A line from seed, the A line being planted 5 to 6 weeks earlier (Pl. 42(*b*)).

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[1] For an up-to-date account of onion seed storage and the various factors affecting the viability of stored onion seed, reference may be made to the recent book by Barton (1961), on *Seed Preservation and Longevity*.—*Ed.*

Hybrid seed of the long-day types is usually produced in northern latitudes where bulbs of the A and C lines may be planted either in the autumn or in the spring. If the two lines do not coincide in their flowering, it is possible to change the flowering time of one line or the other by changing the bulb storage temperature. Most of the lines for hybrid seed production are stored at about 0°C. or slightly above, to hold rotting and sprouting to a minimum, but flowering can be hastened by as much as a week or ten days by storing bulbs at 10° to 12°C. If it is desired to hasten the flowering of the C line in order to produce pollen early, it may be necessary to store only a portion of the bulbs—probably about 10 per cent of them—at the higher temperature. The bulbs from the different storage temperatures can be mixed at planting time; or it may be advisable to plant the C line in the autumn and the A line in the spring, or vice versa.

Not only must the A and C lines coincide in their flowering period, but there must be a large insect population to do the pollinating. The onion has a wide range of insect pollinators, but usually the honey-bee predominates. Growers of large acreages usually provide 3 or 4 hives for each acre of plants. The hives are moved to the edge of the field at about the time the flowers begin to open. Where extremely high temperatures prevail, a shelter is built over the hives, for shade. It may be best not to locate onion seed fields near such crops as alfalfa or clover, as there are indications that bees occasionally desert the onions for these other crops; however, critical information is lacking.

Regardless of how much care is used in the production of the A line, a few male-fertile and other off-type plants are usually found, and it is important that these be eliminated. It is best to rogue early in the morning, before any pollen is shed, as it is then easy to detect plants that have anthers loaded with pollen. Usually there is less air movement in early morning than later on; this is an added advantage, as it is difficult to detect fertile plants when the flower-stems are agitated by strong winds. The entire rogue plant should be pulled up, and the flower-heads cut off and destroyed by burying. If flower-heads are dropped on the ground or at the end of the row, they may continue to flower and shed pollen for several weeks.

E. W. Davis (1960) suggests using marker genes to facilitate the rogueing of onion seed fields. Their use is especially helpful in detecting fertile out-crosses in the A line. An example of the use of a marker gene is illustrated by the inbred B 5546, the seed parent of the hybrid 'Elite'.

When the A and B lines of B 5546 were released by the U.S. Department of Agriculture in 1953, they were heterozygous for perianth colour, i.e. plants with both green and white perianths were present in the population. Later, the A and B lines were made homozygous for white perianth colour, which is inherited as a simple recessive, and were released to the public. The white perianth can be seen in the early bud stage, and any plants in the A line with green perianths are rogues that can be detected and removed before the flowers open; so is the danger of contamination eliminated. Foliage colour can also be used as a marker. Glossy foliage colour is recessive to non-glossy. When the A line has glossy foliage, any out-crosses to non-glossy can be detected early and removed from the A line before the flowers open. Markers such as anther colour and anther length facilitate rogueing after the flowers open. Recessive markers should be incorporated in the A and B lines, and the dominant markers in the C lines.

To prevent the mixing of hybrid seed from the A and C lines at the time of harvest, several procedures are used. When seed of the C line is not to be saved, the seed-heads from this line are sometimes destroyed by mowing (Pl. 40(*a*)) or by disking as soon as pollination has been completed. If seed of the C line is to be saved, the more valuable hybrid seed may be cut first. When seed-stems are lodged and intermingled by strong winds or other forces, the adjacent A and C rows must be separated before harvest, to prevent seed-mixing (Pl. 39(*b*)).

XIV

WEEDS AND THEIR CONTROL

FOR the successful growing of onions, weed control is essential—especially as, during their early development, onions are poor competitors of weeds. Many weed seeds germinate quickly, and the seedlings soon outgrow the young onion plants. Fields may become green with weeds before the onion seedlings reach the surface. Onions are slow to get started, even after the seedlings appear above ground, and for a time they appear barely to hold their own. This is especially true during the flag stage, i.e. after the cotyledon has become detached from the mother seed and before the appearance of the first true leaf. This is the time when the young seedling is becoming established as an independent, growing individual, and it is usually during this time that the more aggressive weeds get the advantage of it. If weeding is impossible because of prolonged rainfall or for other reasons, the crop may have to be abandoned.

In some of the older districts, onions are planted on the same land year after year—primarily because these fields have been kept free from weeds. Usually, however, onions are planted on land where weed control is a continuous battle from the time the seed is sown until the crop is harvested.

In the United States the onion losses from weeds probably approximate those from insects and diseases combined. Hundreds of acres are ploughed under each year because weed control is either impossible or unprofitable. Not only must weeds in the onion fields be controlled, but every means available must be used to reduce greatly the general weed population. Weeds that go to seed reinfest the land; their seeds may lie dormant in the soil for years, germinating and sprouting only when they reach the surface soil, are exposed to light, or obtain the proper temperature, moisture, and oxygen supply. Weed control should be a community effort, public as well as private, because weeds must be controlled along highways, fence rows, ditch banks, and waste land, to prevent reinfestation of cultivated land. These weeds may also harbour various insects and diseases that are a continual threat to crop plants.

METHODS USED TO CONTROL WEEDS

We have at our command many different methods of controlling weeds. Where crops are not involved, weeds can be destroyed by mowing, burning, and the application of oils or other herbicides. Many herbicides are now available that completely destroy all vegetation; however, not all herbicides are satisfactory under every condition.

Certain crop rotations may help to reduce the weed population. Onions should follow crops which require clean-cultivation, or else a hay or grain crop in which the weeds have been smothered or controlled by repeated mowing or by herbicides.

Tillage is still the chief method of weed control. In some countries the hand hoe, which has been used for centuries, is still the most important implement. The large power-operated machines, which are usually found on the large farms, may perform several operations at one time. In addition to cultivating for weed control, they may open ditches between the rows for irrigation, and also apply fertilizers, herbicides, insecticides, or fungicides. Between these two extremes are found many types of implements, such as wheel hoes and garden tractors. Regardless of the kind of implement used, the best time to kill weeds is when they are small. In the irrigated districts of the western United States, beds are sometimes thrown up and irrigated to germinate the weed seeds. When the weeds are still small, the surface of the beds is worked with cutting knives, whereupon the beds are reformed and seeded. Stirring the surface soil exposes the germinating seeds and young seedlings to drying winds and hot sun at a time when they are most easily killed. But regardless of tillage methods, there are usually some weeds in the row that must be removed by hand—an operation which may be very costly.

Chemical control is probably the most promising of the weeding methods. This is a relatively new field of activity, and consequently there are many unsolved problems in it. Reports on the effectiveness of the different herbicides are often at variance. This may be inherent in the chemical itself, in the methods of application, or in the conditions under which the herbicide is applied. Many different environmental factors, such as rainfall, soil type, temperature, humidity, and wind, may influence the results obtained with herbicides, and for this reason their effectiveness may change as environmental conditions change.

The effectiveness of pre-emergence herbicide treatments may be increased by moderate rainfall occurring shortly after application. Heavy rains soon after pre-emergence treatment may reduce the weed kill, and may also cause crop damage. Post-emergence herbicides applied to foliage may have their effectiveness reduced by rain falling soon after application. However, depending on soil type, moderate rainfall several hours after application will usually do little harm.

Soil type influences greatly the depth to which certain chemicals penetrate the soil; penetration is greater in light, sandy soils than in heavy, clay soils or in muck. This is an important factor in pre-emergence treatments.

High or moderate humidity increases the effectiveness of most herbicides that are applied to foliage, because it reduces loss of spray from evaporation and also aids in absorption. Low humidity reduces the effectiveness of herbicide sprays by increasing the rate of evaporation; it also alters the physical condition of the leaf surface, so that penetration of the herbicide is reduced. The disadvantage of low humidity can be partially overcome by using oil or oil–water emulsions instead of water.

Moderate temperatures of 70° to 85°F. are favourable for the spray application of most herbicides. Low temperatures during the week before spraying often slow plant growth and retard herbicidal activity. High temperatures increase losses of volatile herbicides and also increase the possibility of injury to crops from selective herbicides.

Winds cause the irregular distribution of herbicides and greatly increase the hazard of damage as a result of drift to near-by sensitive crops. This is especially true with hormone sprays, but these are seldom used on onions. Ground applications of herbicides should seldom be made during winds of more than 10 to 15 miles per hour. Applications by aircraft should stop when winds become stronger than 6 to 8 miles per hour.

Certain herbicides are extremely poisonous to humans and livestock, and may cause painful burns, nausea, and irritation of the eyes and respiratory organs. For this reason great caution is needed in handling many herbicides. Labels on the container usually list the crops to which the herbicide can be applied, the weeds it can be expected to control, the rates to use, and the precautions to be observed. The instructions on the label should be strictly adhered to. Directions for use should be followed closely, to get the most effective as well as the most economical control.

For all types of herbicides, the correct amount must be applied, and it must be applied uniformly. This means that the sprayer must be in good operative condition. Sprayer output must be determined, for each operation, by careful calibration. Dealers in spray equipment usually provide charts or hand-books that give detailed instructions. In the United States, the U.S. Department of Agriculture and most agricultural experiment stations have publications on weed control equipment that are available for the asking or for a nominal fee.

Chemical weed control is a very specialized field and, like insect control, it is being handled more and more by specialists. In many districts, specialists with the necessary equipment and knowledge supply the herbicide and do contract work at a certain rate per acre. In many places, laws and regulations forbid the use of certain herbicides, and crops containing residues of these may be confiscated or destroyed. Because of the many restrictions in the use of herbicides, it is important to obtain the most up-to-date information from local agricultural advisers. When herbicides are being used for the first time in a new district, they should be tested on an experimental basis. Proceeding cautiously will avoid the danger of heavy losses. A useful guide to chemical weed control has been published by the U.S. Department of Agriculture (Anon., 1958).

How Herbicides Work

The objective in chemical weed control is to kill the weeds but not the crop. A herbicide may be selective, i.e. when applied to both weeds and onions, it will kill the weeds but leave the crop unharmed. Selectivity is usually only relative; thus almost any herbicide will kill the crop if applied in sufficient concentration. The onion plant is fairly well adapted to the use of foliar selective herbicides. Its stem apex is below ground and, as the plant develops, is surrounded by an increasing number of scales. Most broad-leafed weeds have their stem tips above ground and thus are vulnerable to killing by herbicides. Onion foliage is also covered with a waxy secretion that causes a spray to form in droplets or to bounce off. The amount of wax on the foliage varies with the cultivar, age of the leaf, and growing conditions; consequently, not all cultivars react similarly to any given herbicide, nor does any single cultivar react in the same manner under different growing conditions or at different stages of its growth. A herbicide may not be selective, but may be applied in such a way as to avoid injury to the crop. For example, onion foliage can be protected by using shields and directing the herbicide spray towards weeds at the base of the plant.

Herbicides are usually applied as sprays—either to the foliage of the growing weeds or to the soil surface. It may be that only the part of the plant which is actually contacted by the spray will be killed immediately, but as a result of this contact the entire plant dies. Other herbicides may be translocated within the weed, so that the stem tip is killed.

So far no one herbicide has been found that will do equally well under all conditions, but a number of them are now being used rather extensively and effectively on onions. It should be pointed out that most herbicides are only effective on certain types of weeds, and that those weeds which are not killed may increase and become a real problem—especially when the same herbicide is used repeatedly.

Herbicides That are Commonly Used

CIPC (isopropyl N-(3-chlorophenyl) carbamate)

This chemical, which is relatively insoluble in water, is marketed in an emulsifiable organic solvent containing 4 lb. of CIPC per gallon. Mixed with water, this may be applied at either low or high gallonage rates.

Lachman (1953) found that CIPC was an excellent pre-emergence herbicide for onions that had been raised from dry sets (Table XXVII).

TABLE XXVII

EFFECT OF PRE-EMERGENCE CIPC TREATMENTS ON WEED CONTROL AND YIELD OF 'EBENEZER' ONIONS GROWN FROM DRY SETS: PLANTED ON APRIL 18th, TREATED APRIL 21st, AND HARVESTED JULY 15th. WEED DATA AND ONION HEIGHTS TAKEN JUNE 20th, AMHERST, MASSACHUSETTS

(Lachman, 1953)

Treatment	Amount per acre (lb.)	Weeds per yd. of row (no.)	Size of weeds[1]	Height of onion (in.)	Yield per plot (lb.)
CIPC	2	21·6	7·3	16·3	31·0
"	4	10·6	8·3	17·0	37·3
"	6	5·6	9·0	15·6	33·3
"	8	5·3	9·0	17·3	37·0
Check	—	94·6	1·0	17·3	30·3
L.S.D.[2] at 5% level	—	8·4	1·2	1·8	N.S.[3]
L.S.D.[2] at 1% level	—	12·1	1·7	N.S.[3]	N.S.[3]

[1] 1 = large weeds → 9 = small weeds.
[2] Least significant difference.
[3] Not significant.

Plots, consisting of 6 rows 15 ft long and 15 in. apart, were laid out on a heavily fertilized, very fine sandy loam. CIPC at rates of 2, 4, 6, and 8 lb. per acre, in 100 gal. of water, was applied 3 days after planting the sets. CIPC not only reduced the weed stand but also the weed size. When it was applied at the rate of 6 to 8 lb. per acre, weed growth was suppressed satisfactorily for nine weeks.

For onions grown from transplants in central California, G. N. Davis (1957) suggests using CIPC at the rate of 4 lb. per acre in 60 to 100 gal. of water applied 1 to 3 weeks after transplanting.

On the Everglades peat land of Florida, Guzman & Wolf (1955) used CIPC for pre-emergence (spray) and post-emergence (pellets) weed control on three cultivars, Granex, Texas Early Grano, and Early Grano. The pelletized CIPC (30–60-mesh clay granules impregnated with 20 per cent CIPC by weight) was used after onion seedling emergence, as the pellets roll to the ground without prolonged contact with the onion leaves. After the seed was planted 1 in. deep on December 2nd, the land was rolled and three treated plots were sprayed at rates of 12, 16, and 20 lb. of CIPC per acre. For the post-emergence treatment, pelletized CIPC was broadcast by hand on these same plots at the rate of 10 lb. per acre on March 17th, and then twice more at 3-weeks intervals.

Two check plots were used. In one the weeds were removed by cultivation only. The other check plot was given two post-emergence sprays of 10 lb. per acre of NIX (sodium isopropylxanthate) in addition to the three applications of pelletized CIPC. The NIX spray was directed at the base of the onion plants by a machine which cultivated between the rows at the same time.

All treatments used were about equally effective in the control of weeds; however, 3½ months after the pre-emergence treatment, there were significantly more weeds in the untreated check plots than in the treated plots. Within 2 to 3 weeks after hoeing the untreated check plots, a new crop of weeds appeared, while the herbicide-treated plots remained almost free from weeds for 3 months. The frequent post-emergence treatments with CIPC pellets continued to keep the treated plots free from weeds. The residual effect of the pelletized CIPC lasted for only 3 weeks.

The pre-emergence control of weeds with sprays of 12, 16, and 20 lb. of CIPC per acre was excellent. The residual toxic effect lasted about 3 months. The differences among these treatments were slight; 12 lb. per acre was sufficient for good control. Visible temporary damage occurred in the plots where 16 and 20 lb. were used, but this damage later disappeared. The stand of onions was decreased somewhat as a result of the heavier applications.

For effective control of weeds, pelletized CIPC must be applied before or at the time of weed seed germination; for once weeds are established, even though they are small, the effect of pelletized CIPC is greatly reduced. In the above tests, frequent rains before and after the pre-emergence treatments maintained a relatively high moisture content in the surface soil, and the temperature was fairly low during the first 3 months. Under these climatic conditions, CIPC was very effective against weeds, and no differences in response to CIPC appeared among the three cultivars which were tested.

The check plot which received the two post-emergence, directional applications of 10 lb. per acre of NIX at the time of cultivating between the rows, supplemented with three applications each of 10 lb. of pelletized CIPC per acre, also showed good weed control and no reduction of yield of onions.

In another experiment on Everglades muck soil in Florida (Wolf & Guzman, 1955), CIPC was used only for pre-emergence, while other chemicals were used for post-emergence applications. These treatments, with their comparative yields, are given in Table XXVIII. The same cultivars were used as in the preceding experiment. All chemicals were applied as a spray, with a pressure of 30 lb. per sq. in. and in 90 gal. of water per acre—except Monuron, which was in 30 gal. The spray equipment was attached to an Ariens Tillivator (cultivating machine—*see* Wolf & Guzman for details). The post-emergence sprays were applied to the base of the onion plants simultaneously with the cultivation of the space between the rows.

Pre-emergence treatment with CIPC gave effective weed-control for about 6 weeks, and eliminated one hand-weeding. All the four chemicals

TABLE XXVIII

EFFECT OF PRE-EMERGENCE AND POST-EMERGENCE WEED TREATMENTS ON ONION YIELDS, BELLE GLADE, FLORIDA

(Wolf & Guzman, 1955)

Lot	Treatment Pre-emergence	 Post-emergence	Yield per plot (lb.)
1	Hand weeding & tillage	Hand weeding & tillage	112·2
2	CIPC, 12 lb./acre	,, ,, ,, ,,	146·4
3	,, ,, ,,	$2\frac{1}{2}\%$ H_2SO_4 (by vol.), 2 applications	151·2
4	,, ,, ,,	NIX, 10 lb./acre, 2 applications	135·0
5	,, ,, ,,	KOCN, 12 lb./acre, 2 applications	143·4
6	,, ,, ,,	Monuron, 2 lb./acre, 2 applications	117·3
Least Significant Difference at 5% level			12·9
Least Significant Difference at 1% level			17·7

used as post-emergence sprays gave good weed control. Monuron gave a little better control of grasses, and its residual effect lasted a little longer than the others. All the plots received two hand-weedings after the onion plants became too large to be cultivated. The three cultivars behaved similarly and showed no ill-effects from the chemicals used.

Behrens *et al.* (1960) found that CIPC, applied at a rate of 4 to 6 lb. per acre, gave good weed control as a pre-emergence spray on mineral soils in Minnesota. On muck soils, 8 lb. was necessary to obtain control. CIPC was especially effective in controlling purslane (*Portulaca oleracea* L.) and smartweed (*Polygonum* sp.). Where weeds emerge before the onions, effective control has been obtained by a combination of 4 lb. of CIPC in 50 gal. of Stoddard solvent per acre. For such weeds as purslane, on muck soils, post-emergence sprays of 6 to 8 lb. of CIPC per acre after emergence of the first true onion leaf, and 8 lb. per acre directed as a basal spray on plants with three or more leaves, gave excellent control.

In Australia, State of Victoria, Kefford & Wright (1958) found that CIPC could be used both as a pre-emergence and post-emergence spray for onions. In Victoria, seed is drilled in rows 9 to 18 in. apart during May, June, and July. Seedlings emerge in about 2 to 3 weeks, taking longer as the weather becomes cooler. Brown Globe and Australian Brown are the two main cultivars. These workers indicate that the pre-emergence CIPC spray should be at a rate of 2 to 4 lb. per acre, the lighter rate being for sandy soils and cold, wet conditions. Rates for post-emergence sprays may be from 3 to 6 lb. per acre. CIPC is more effective at low temperatures than at high ones and is, therefore, a good winter-weed killer. The residual effect is long-persistent during the winter months, but in hot weather the CIPC evaporates or decomposes and the residual effect is rapidly lost.

For ideal results, pre-emergence sprays should be applied when the weed seeds are germinating and the onion seedling is at the point of emerging from the soil. Post-emergence sprays should be applied as soon as the effect of the pre-emergence treatments wears off.

Minges *et al.* (1960) make the following suggestions for the control of weeds in onions on muck soil in New York State. Apply 4 to 8 lb. of CIPC per acre before seedling emergence. Directed sprays may be applied to the soil after onion tops are tall enough to escape the spray. CIPC is excellent for controlling chickweed (*Stellaria media* (L.) Cyr.) and purslane (*Portulaca oleracea* L.), but only fair for other weeds. A mixture of 4 to 8 lb. of CIPC and 6 lb. of CDAA (*see* below) per acre is useful as a directed spray just before the tops fall over. When sprayed on the entire soil surface, it will control weeds for the remainder of the season.

CDAA (2-chloro-N,N-diallylacetamide)

CDAA is formulated as an emulsifiable concentrate containing 4 lb. of the active chemical per gal. It is designed primarily for pre-emergence control of annual grasses, and is less effective on broad-leafed weeds.

Behrens *et al.* (1960) state that CDAA, applied before weed and crop emergence at the rates of 4 lb. per acre on mineral soils and 6 lb. on muck soils, gives good control of annual grasses, but variable control of annual broad-leafed weeds.

For emerging weeds in both mineral and peat soils in Oregon, Duncan & Crabtree (1961) suggest using 6 lb. of CDAA in 20 or more gal. of water per acre. For killing growing weeds in seeded or set onions, they recommend the same formulation for application after the onions have 3 true leaves. The weeds should be in the cotyledon stage, and the annual grasses should not be beyond the 2-leaf stage. Duncan & Crabtree indicate that this herbicide is more effective on grasses than on broad-leafed weeds.

Workers at Cornell University (Minges *et al.*, 1960) suggest the use of 6 lb. per acre of CDAA on muck soil prior to onion emergence, but caution that severe injury may result if rains of ½ in. or more occur within 2 days after treatment. They report that CDAA is very toxic to onion foliage, and that directed sprays are to be used after the 3- to 4-leaf stage. The residual effect of CDAA is less than that of CIPC.

KOCN (potassium cyanate)

KOCN is a white, water-soluble powder. It is a selective herbicide that is used as a spray, and is effective only in killing small and tender weeds. KOCN can be used as a pre-emergence contact weed-killer. It should not be applied to onions in the flag stage, but can be applied as soon as the true leaves appear, as they are tolerant to the spray and can be sprayed without injury each time a new batch of weeds appears. KOCN should be applied when the soil is moist but the weeds are dry and growing actively. After the first 2 or 3 true leaves appear, KOCN can be applied at the rate of 10 to 16 lb. in 50 to 100 gal. of water per acre. After onions have started to bulb, the amount should be increased to 16 to 20 lb. per acre. A low-pressure spray of 20 to 50 lb. per sq. in. is best. The herbicide is most effective at temperatures above 75°F.

Filman & Shoemaker (1952), in Ontario, Canada, recommend 8 to 10 lb. of KOCN in 50 gal. of water per acre as a pre-emergence spray for onions. For post-emergence, 8 lb. in 50 gal. of water is recommended, or proportionately less if applied in bands. Leaves should be dry when sprayed, and at least 4 hours of dry weather is needed after application. Onions damaged by hail, wind, drought, frost, insects, and disease should not be sprayed with KOCN until normal growth is resumed. The foliage of certain cultivars seems to be more sensitive to KOCN injury than is that of others.

SULPHURIC ACID (H_2SO_4)

Sulphuric acid, a heavy, oily liquid that is miscible with water in all proportions, was one of the earliest herbicides to be used on onions, and is still used rather extensively, although many avoid it because it is dangerous to handle, injurious to skin and clothing, and corrosive to metals.

As a pre-emergence spray, a 3 to 5 per cent (by weight) solution of sulphuric acid in water, applied at the rate of 100 gal. per acre, will kill a wide variety of annual grasses and broad-leafed weeds. Post-emergence spraying is best delayed until after the flag stage, or when the first true leaves appear, when a 2 to 3 per cent solution may be applied. At a still later stage, when the onions start to bulb, a 3 to 4 per cent solution may be used.

Sulphuric acid kills broad-leafed weeds best at the time when their first true leaves are expanding between the cotyledons. To avoid dilution of the spray, it should be applied when the weather is bright and the crop and weeds are dry.

Ordinary spraying equipment is usually unsuitable for sulphuric acid spraying, as the metal parts are corroded by the acid. Special equipment must be used that is resistant to acid. There are a number of important precautions to be observed in the preparation and use of sulphuric acid spray. About half of the water needed should be put into a wooden barrel and the required amount of concentrated acid poured into the water in a thin stream, while the mixture is stirred thoroughly with a wooden paddle. *Never pour water into the acid.* Mixing should be done in a separate tank: if the mixing is done in the machine tank, the concentrated acid, being heavier than water, will sink to the bottom of the tank and, without becoming diluted, get into the pipes leading to the nozzles. Rubber gloves, rubber coats, and rubber boots, will protect clothing and skin. Goggles should be used to protect the eyes, and a smear of acid-resistant cream or petroleum jelly to protect the face.

Some of the above problems with sulphuric acid can be avoided by the use of machines that are designed to extract the concentrated acid directly from its original container by an ejector placed immediately following the pump. This minimizes handling of the acid and limits its contact with the spray equipment.

OILS FOR PRE-EMERGENCE TREATMENT

Several oils are being used as pre-emergence sprays on direct-seeded onions. Stoddard solvent is applied at the rate of 60 to 80 gal. per acre. Diesel fuel oil for weed killing is readily available from oil dealers. It is less refined than automotive diesel oil and, therefore, more toxic to plants. It is applied at the rate of 20 to 40 gal. per acre, but this rate can be reduced by limiting the spray to the seed row. Other weed-killing oils for onions are sold under various trade names. Application of oil is best delayed until a few onion seedlings emerge in the earliest part of the field. Although these will be killed, this method gives the best weed control.

MONURON (3-(p-chlorophenyl)-1,1-dimethylurea)

Where climatic and soil conditions are suitable, Monuron is one of the better herbicides for controlling weeds among onions that are being grown for seed. On mineral soils in northern Utah, Hawthorn *et al.* (1957) found that Monuron, applied at the rate of 2 lb. per acre in 80 gal. of water either shortly after the mother bulbs were planted in early spring or later when the seed-stalks were beginning to elongate, was an effective herbicide for the control of annual broad-leafed and annual grassy weeds. When applied shortly after the mother bulbs had been planted, the herbicide was sprayed evenly over the entire soil surface. When it was applied as the seed-stalks were elongating, the entire surface was covered, but the application was made between the rows, and the spray was so directed that only the lower part of the plants (2 to 3 in.) was hit. Monuron was most effective when rain or a sprinkler irrigation of 1 to 1½ in. followed shortly after it was applied. Hawthorn *et al.* caution against the planting of small grain when the preceding crop was treated with Monuron, because in some years the residue may be injurious. When Monuron was used, the onion seed-stalks had a tendency to lodge, which caused some loss of seed and made harvesting more difficult.

XV

DISEASES AND THEIR CONTROL

LOSS from disease is a constant threat regardless of where onions are grown, and whether large bulbs, dry sets, transplants, or seeds, are being produced. Chemicals have given excellent control of onion smut, and high resistance to pink-root has been developed by their use; of the control of most diseases, however, good cultural practices, proper harvesting, curing, storage, and sanitation, are necessary. Much of the material which is used in this chapter has been obtained from numerous contributions made by Dr J. C. Walker and his associates at the University of Wisconsin, where a study of onion diseases was a major project for many years.

FUNGUS DISEASES

ONION SMUT (Causal Organism: *Urocystis cepulae* Frost)

In the United States, onion smut is prevalent in all of the northern onion-growing States, but it is not found in the southern districts, even though it must have been introduced there many times in dry onion sets and possibly by other means.

The disease is evident soon after the plants appear above ground. Infected seedlings show a slight curvature of the cotyledon, accompanied by some enlargement of the affected part. If infection occurs near the knee of the cotyledon, the cotyledon may mature or die, preventing further invasion by the parasite. If infection occurs at or near the stem plate, the parasite soon penetrates the embryonic region from which the leaves originate, and continues to grow and infect each successive leaf as it arises. Mature spores are found in conspicuous dark blisters which break and expose the black spore-mass (Pl. 43(*a*)). Although a few of the infected seedlings may outgrow the disease, most of them die within 3 to 5 weeks after germination, often leaving thin stands. Some diseased plants survive until mid-season or harvest, but few infected plants ever recover completely (Pl. 43(*a*)). Infected mature bulbs are characterized by slightly raised, brown to black lesions which are usually situated near the base of the outermost fleshy scale but sometimes as deeply as the third or fourth scale. Smutted bulbs do not rot in storage, but they shrink more rapidly than healthy bulbs and are more easily attacked by other organisms.

The absence of onion smut under high-temperature conditions is probably due to a combination of cultural practices and environment. In warm climates, such as those of Egypt and the southern United States, onion seed is usually sown in the late summer or early autumn, when temperatures are high. The plants are susceptible to infection only from shortly after the seed starts to germinate until about the time when the first leaf emerges from the cotyledon. Infection takes place at temperatures as low as 10° to 12°C. and occurs easily at 25°C. Above 25°C., infection rapidly declines, until at 29°C. it becomes completely inhibited. High temperatures do not cause a corresponding decrease in the growth-rate of the onion plant, but, instead, the seedling grows rapidly and has, therefore, only a short period of susceptibility. Also, high temperatures at the time of germination may inhibit or greatly retard the growth of the smut organism. Onion smut has been observed, however, in some areas where day-time temperatures are quite high. Kendrick & Stevenson (1949) reported a severe infection of onion plants in August in the San Joaquin Valley of California, where the daily maximum air temperatures were generally above 30°C. Low night temperatures and frequent irrigations probably kept the soil sufficiently cool to permit infection.

Smut may be avoided in disease-free soils by preventing its introduction on onion refuse, on transplants or sets, or on farm machinery. It is good practice to burn all the refuse from onion storage houses. As only seedlings are susceptible to infection, transplants or sets that are free from smut will not become infected when planted on smut-infested soil.

The chief means of control of onion smut is the formaldehyde-drip method, in which a stream of dilute formaldehyde is applied in the furrow with the seed. The formaldehyde vapour temporarily disinfects the soil layer over the seed, protecting the seedling during its susceptible period. The best results have been obtained with a solution of 1 pint of 40 per cent formaldehyde in 16 gal. of water, applied at the rate of 200 gal. per acre. In another formula which is now commonly used, 1 pint of 40 per cent formaldehyde in 8 gal. of water is applied at the rate of 100 gal. per acre. The effectiveness of the treatment is sometimes reduced if heavy rain immediately follows the application. Formaldehyde-drip attachments may be used in single drills or in gangs of two or more. As this method is rather cumbersome, other means of control continue to be investigated.

In New York State, smut has been controlled by stirring onion seed in a 5 per cent solution of methyl cellulose and then coating with Thiram (tetramethyl thiuram disulphide). Where seed was used at the rate of 5 lb. per acre for large-bulb production, the best results were obtained with about 1 lb. of the fungicide coated on to 1 lb. of seed (Newhall, 1944). On upland soil in districts of southeastern Wisconsin where onion sets are grown, $\frac{1}{10}$ lb. of Thiram is applied to 1 lb. of seed, without a sticker (Larson & Walker, 1953).

All known cultivars of *Allium cepa* are susceptible to smut. The Japanese bunching (Welsh) onion, *A. fistulosum*, is highly resistant, as is also the amphidiploid 'Beltsville Bunching'.

PURPLE BLOTCH (Causal Organism: *Alternaria porri* (Ell.) Cif.)

This disease occurs in many sections of the United States, and in Puerto Rico, Cuba, Mexico, and many other countries. Heavy losses may occur to onions growing as well as to the bulbs in storage. Warehouses filled with 'Sweet Spanish' bulbs have had to be discarded a few weeks after storing because of purple blotch, although losses therefrom are seldom so severe. The climatic conditions which favour the development of purple blotch are still not well understood.

The germinating conidia enter the plant through wounds, and through the stomata of healthy leaves and seed-stems (Angell, 1929). About 4 days after infection, greyish, deep-sunken lesions are evident. In the centre of these lesions, small dark spots appear which later enlarge into purplish areas that are separated from the surrounding healthy tissue by narrow, light-coloured zones. Later, concentric light and dark zones appear over part or all of the purple area, the darker zones being the areas occupied by the conidia. The lesions may eventually reach a length of 10 cm. and partly or wholly encircle the stem or leaf, finally killing it (Pl. 43(*b*)).

Infection of the bulb usually occurs late in the season, when the plants are nearly mature. The fungus may enter through wounds that are made at the time of harvesting, but most of the infection is through the neck. It causes a semi-watery rot and shrinkage of the fleshy bulb-scales, which take on a deep-yellow to wine colour, later becoming dark-brown to black. Desiccation follows, and the diseased scales become papery. Often only one or two scales are affected; but, on the other hand, the entire bulb may be destroyed.

Very little is known about the control of purple blotch except that the foliage of certain cultivars is more resistant than that of others. Resistance seems to be associated with a heavy deposit of bloom or wax on the leaves and seed-stems. Of the short-day onions, 'Red Creole' is much more resistant than 'Grano' and 'Bermuda'; of the long-day types, the Yellow Globes are much more resistant than the Spanish types.

DOWNY MILDEW (Causal Organism: *Peronospora destructor* (Berk.) Casp.)

Onion mildew was first reported from England in 1841 but seems to be world-wide in distribution. It has been reported from Africa (Egypt, South Africa, and Mauritius), from the Americas (Canada, the United States, Bermuda, Venezuela, Brazil, Colombia, Uruguay, and Argentina), from almost all parts of the British Isles, very widely from Eurasia (Norway, Sweden, Denmark, Germany, the Netherlands, Switzerland, France, Spain, Italy, Romania, Bulgaria, Greece, Cyprus, Latvia, the

U.S.S.R., Palestine, Iraq, China, and Japan), and from Australia. Downy mildew has been reported on the common onion, the Japanese bunching (Welsh) onion, leek, garlic, and chives—also on *Allium nigrum* L., *A. ursinum* L., and *A. oleraceum* L.

Weather is an important factor in determining the extent and severity of mildew. Heavy dews and foggy or rainy weather favour its rapid spread, and when prolonged rainy spells occur in the summer, this disease can be very destructive.

The first indication of a mildew infection is a furry, violet covering on the outside of the leaf or seed-stem—a symptom that is especially conspicuous when the foliage is wet with dew. One or two days later the diseased portions become pale-green, then yellow, and finally they collapse. When a large portion of the leaf surface is destroyed, yields are reduced and the bulbs neither mature properly nor keep well in storage. Some of the plants become systemically infected, and, if these are saved as mother bulbs, they may serve as sources of inoculum in the seed crop. In California, Yarwood (1943) found very few systemically infected bulbs, even from fields that were heavily infected with mildew. In England, according to a report by the Ministry of Agriculture and Fisheries (Anon., 1928), systemically infected bulbs are of frequent occurrence. The tree onion and potato onion are also hosts to the perennial mycelium.

After a period of storage, systemically infected bulbs become soft and shrivelled, and the outer fleshy scale becomes partly or wholly amber in colour, wrinkled, and watery. The underlying scales and stem plate may appear healthy, but in reality are permeated by the fungus. Many bulbs die during the winter, but often the infected ones remain comparatively firm and sprout prematurely. Plants developing from such infected bulbs can be detected by their light-green foliage, and should be destroyed.

The injury to the crop which is being grown for seed will depend on its stage of development at the time of infection. Mildew may appear on the leaves of the seed crop in early spring, and then disappear for the remainder of the season if the weather is dry. Later, infection may destroy the primary seed-stalks but allow the secondary ones to grow normally. If conditions remain favourable for the spread of mildew, the secondary seed-stems may also be damaged or destroyed.

Some control may be obtained by planting the crop so that the foliage will dry rapidly after rains, dews, and fogs: use only well-drained land, run the rows in the same direction as the prevailing winds, and avoid windbreaks or other protection. Commercial seedsmen in the United States have avoided mildew by locating their seed fields in areas where there is very little fog or dew, and only limited summer rainfall. In New York State, control of mildew was aided by the eradication of the tree onion, an over-wintering host of the fungus.

Only non-infected bulbs should be used for planting stock, and the seed fields should be rogued early to eliminate systemically infected plants. If infected bulbs must be used, the fungus in the bulbs can be destroyed by dry-heating for 4 hours at 41°C.; heating as long as 32 hours at 41°C. is not injurious, so the treatment has a wide margin of safety (Yarwood, 1943).

In small plots which are to be used for seed production or for breeding, it is possible to control mildew by pruning. At Davis, California (H. A. Jones *et al.*, 1939), mildew appeared on one occasion very early in a small increase-plot of 'Stockton G 36'. The foliage was luxuriant and practically every leaf was infected by March 21st, at which time seed-stems were just emerging through the surrounding sheaths. To eliminate the source of inoculum, all of the leaves were trimmed off and the seed-stems were left exposed. These stems continued to grow, very little infection occurred, and a good crop of seed was harvested. This method is impractical for large seed-fields, but at times it may save valuable breeding material or small increase-plots.

In the United States, the use of sprays or dusts has generally not given satisfactory control of onion mildew. In Holland, the best results were obtained by spraying with 2 per cent Zineb (zinc ethylene bisdithiocarbamate), applied at the rate of 150 l. per ha., with the addition of a commercial spreader (Doorn *et al.*, 1954). On the main-crop onions, the treatment is first carried out before the symptoms appear, and is repeated thereafter at 7- to 10-day intervals, according to weather conditions. In Australia, Zineb, used at the rate of 1½ lb. to 100 gal. of water plus a spreader, controlled mildew on both the bulb and seed crops if spraying started before mildew appeared and was repeated thereafter every 10 to 14 days (Doepel, 1956).

PINK-ROOT (Causal Organism: *Pyrenochaeta terrestris* (Hans.) Gorenz, J.C.Walker, & Larson)

Taubenhaus & Mally (1921), the first workers to describe pink-root in the United States, stated that it was very destructive in southern Texas and had been known there for at least 15 years. Since that time it has been reported from various districts in the United States and from many other countries.

The host-range of pink-root includes the common onion, the Japanese bunching (Welsh) onion, leek, garlic, shallot, chives, and many other cultivated crops and native plants. It is not uncommon to have pink-root appear on onions that have been grown on land which has never before been planted to this crop.

As the name indicates, the roots are the parts affected. As they become infected they turn pink, shrivel, and die, whereupon the plant sends out new roots, which in turn become infected and die. This may continue throughout the entire growing-season. Affected plants are usually not killed, but the tips of the leaves often wither and die, while the injury to the root system causes the development of scallions and small bulbs, and yields may be greatly reduced (Pl. 43(*c*)). Susceptible cultivars, however, such as Early Grano, may be killed in the early seedling stage when they are grown on badly infested soil.

Where onions are grown as a winter crop, the seed is usually sown in warm soil; under these conditions the pink-root fungus is active and the seedlings become infected early. If the soil remains warm, the fungus may be active throughout the winter; if the soil is sufficiently cool, the fungus may be inactivated for a time. When onions are grown as a summer crop, seed is usually planted in early spring, when the soil temperatures are low, and the crop may be well advanced before the soil temperatures are high enough to permit infection. Several workers have shown that the optimum temperature for the growth of the fungus is between 24° and 28°C. The fungus is active both in acid and alkaline soils, and disease development in sand cultures is not affected by a change in pH within the range of pH 4 to 8 (Gorenz *et al.*, 1949).

The control of pink-root is very difficult when once the soil becomes infested, and the only practical method is either to use a long rotation or to plant resistant cultivars. In southern Texas, the cultivars Excel, L36, L365, Eclipse, Texas Hybrid 28, and Early Crystal 281, all produce excellent crops on highly-infested soil. Bunching-type onions which show considerable resistance are the *Allium fistulosum* hybrids such as 'Louisiana Evergreen' and 'Beltsville Bunching', and cultivars of *A. fistulosum* itself.

If resistant cultivars are not available, onions should be planted on pink-root-infested land only after a rotation period of 3 years or longer. When the crop is grown for transplanting, seed-beds should be on land that is free from the pink-root fungus—preferably on land that has not grown onions previously. This is very important, as seedlings with diseased roots will inoculate the soil wherever they are planted.

WHITE-ROT (Causal Organism: *Sclerotium cepivorum* Berk.)

This disease was first described by M. J. Berkeley in England in 1841. It has been reported from Africa (Egypt, Southern Rhodesia, South Africa), from the Americas (Canada, the United States, Brazil, Colombia, Argentina), from the British Isles (England, Northern Ireland, Scotland, Wales), from Eurasia (Denmark, the Netherlands, the Azores, Spain, Italy, Czechoslovakia, Romania, Cyprus, the U.S.S.R.), and from Australia, Tasmania, and New Zealand. It may be destructive on the common onion, shallot, garlic, Japanese bunching (Welsh) onion, and leek.

The first symptom of the disease is a yellowing and dying back of leaf tips; the yellowing and dying back then progresses down the leaf-blades (Walker, 1924). The rate of decline depends largely upon environmental conditions. Both roots and leaf-bases are attacked. The roots are gradually destroyed, and there is a semi-watery decay of the scales and an abundance thereon of superficial, white, fluffy mycelium. Sclerotia form early and are black, spherical, hard, and 0·5 mm. or less in diameter. They are developed either on the surface or within the tissue. If bulb infection occurs late and is carried into storage, decay will continue.

The fungus probably over-winters in the form of sclerotia, which start growth when the temperature and moisture conditions become favourable. In the absence of host plants, the fungus is known to remain viable in the soil for several years. The disease progresses most rapidly at 10° to 20°C.; at 24°C. or above, it is inhibited (Walker, 1926). In the northern United States, the most favourable time for rapid progress of the disease is during the first half of the growing-season. In the South and along the Pacific Coast, ideal conditions probably continue over a much longer period.

As far as is known, satisfactory control methods have not been developed. Growing seedlings and sets for transplanting on non-infested soil will help to prevent the spread of the disease, and a long rotation will also help to reduce the amount of infection and injury. In England, drilling in mercurous chloride with the seed gives considerable control.

BOTTOM ROT OR BASAL ROT (Causal Organism: *Fusarium oxysporum* Schlecht.)

Basal rot has been reported from most of the older onion-growing regions of the United States, as well as from Japan, Egypt, and Spain, and is, no doubt, widespread. *Fusarium* species are soil inhabitants, and infection is usually believed to follow injury, such as is caused by maggots, cultivation, or pink-root. Kehr *et al.* (1962), however, showed that all of the isolates of *F. oxysporum* f. sp. *cepae*[1] tested proved to be primary invaders of onion seedlings at the temperatures used (20° to 38°C.).

Field symptoms usually do not appear until the soil has become warm. At first there is a progressive yellowing and dying-back from the tips of the leaves; the aerial parts may die in 1 or 2 weeks, or decay may extend over a much longer period. Plants that are infected when young may continue to grow until harvest time. When the disease is evident above ground, decay has already started at the stem plate. The roots may turn pink and gradually decay, until eventually the entire root system disappears. A semi-watery decay, affecting the fleshy scales, starts from the base and progresses upwards, and with early infection, decay may be almost complete by harvest time. Infections occurring about harvest time may continue in transit and storage (Pl. 44(*a*)), until only dry shrivelled 'mummies' remain (Walker & Tims, 1924).

The fungus is able to produce the disease at temperatures of from 15° to above 30°C., with an optimum at about 28°C. Below the optimum the disease is progressively slowed until, at 12°C., the growth of the fungus seems to be inhibited (Walker & Tims, 1924). As a storage disease, basal rot is most active at or above room temperatures. At about 30°C., the tissues decay and dry rapidly; at 20°C. decay is rapid, but the tissues remain watery for a longer time than at higher temperatures; at about 15°C. the rate of decay is very slow, but premature sprouting is evident; at around 8°C., rotting is slight, but sprouting stimulated by the decay is marked.

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[1] *See* footnote p. 95.

Crop rotation should help to control the disease. G. N. Davis & Henderson (1937) showed that resistance to basal rot could be improved by selection.

BLACK MOULD (Causal Organism: *Aspergillus niger* Tiegh.)

Black mould is a rather widespread fungus that seems to persist indefinitely as a saprophyte on organic matter in the soil. As a facultative parasite, it causes one of the most destructive storage and transit diseases of onions in Texas, Louisiana, and California. It is often confused with onion smut; but the black powdery masses of spores of black mould are borne on the exterior of the scales or between the outer scales and, in contrast to those of onion smut, can be rubbed off easily (Pl. 44(*b*)). The affected scales slowly shrivel and finally become brittle.

Under field conditions, coloured cultivars seem to be more susceptible than white ones; Australian Brown and Red Creole, especially, appear to be very susceptible. Those chemical substances which provide resistance to smudge and neck-rot in coloured onions may contribute to black mould susceptibility (Hatfield *et al.*, 1948). Dry conditions favour black mould, while moist conditions favour smudge and neck-rot (Owen *et al.*, 1950).

Control measures for black mould have not been developed. Crop rotation may help to prevent field infection, and storage of bulbs at about 0°C. should check its spread.

NECK-ROT (Causal Organisms: *Botrytis* spp.)

Neck-rot has been reported to be caused by three different species of *Botrytis*: *B. allii* Munn, *B. byssoidea* J.C.Walker, and *B. squamosa* J.C.Walker. The neck-rot caused by *B. allii*, commonly called grey mould neck-rot, is probably the most widely distributed, and with little doubt the most destructive, disease of onions in storage. In addition, it may cause decay of onion bulbs in transit and greatly reduce onion seed yields. *Botrytis* disease of onions was first reported in Germany in 1876, in Italy and France in 1894, and in America in 1890.

Although infection of the bulbs with the neck-rot fungus usually takes place in the field, it seldom becomes evident until the onions have been topped, placed in bags or crates, and cured for a few days in the field. Crops that appear healthy at the time of harvesting and topping may become practically 100 per cent infected while still curing in the field. As a rule, however, in the northern or storage-type onions, the disease does not become evident until some time after the bulbs have been placed in storage.

A softening of the scales usually begins at the neck, the flesh has a water-soaked appearance, and there is a definite demarcation between healthy and diseased tissue. Growth of the fungus continues, sometimes for several months, until the entire bulb is rotted; sprouting may accompany rotting, and often the bulb becomes dry and 'mummified'. Under certain conditions a greyish mycelial mat, which consists of conidiophores and conidia, develops on the surface of the scales. On the surface, or slightly embedded in the older decayed tissue, sclerotia appear—first as whitish, compact masses of mycelium and later as hard, kernel-like bodies (Pl. 45). If bulbs in storage are kept dry, the disease does not spread to other bulbs; but under moist conditions, considerable secondary spread may occur.

Neck-rot is usually most severe when moist conditions prevail just before and during harvest, and while onions are curing in the field. The disease is more severe in mild than in pungent types of onions, but in the mild class, there is no difference between coloured and white onions. In the pungent class, however, the coloured cultivars have significantly less neck-rot than the white ones (Owen *et al.*, 1950).

In Holland, Doorn (1955) reports that onions probably become infected when spread on the ground to dry after harvesting. To check the disease in onions that had been harvested when the leaves were still partly green, artificial drying at 40°C. was most beneficial when used 7 to 10 days after the onions were pulled.

Observations seem to indicate that cultivars with small necks have less neck-rot because small necks cure better than thick necks. Also, cultivars that mature early, while temperatures are still high, have less neck-rot than those that mature late; early maturity is especially important in the North, where late cultivars may encounter unfavourable curing conditions.

Walker (1959) advises artificial curing of white onion sets if neck-rot has started to appear. The sets are placed in a drying room, in the shallow slatted trays that are used for onion set curing and storage. Warm air is blown through these trays for several hours until the neck tissue of the onions is thoroughly dry. If the neck-rot fungi have not advanced very far, such drying of the necks stops their growth.

In the United States, much of the bulb crop to be stored is harvested by machine, loaded in trucks, and elevated into storage rooms, where the onions may be placed 10 to 12 ft deep on slatted floors. To prevent loss from neck-rot, heated air is forced through the piles of onions until the bulbs are well dried.

In the seed crop, the neck-rot organism causes greater losses than is generally recognized. White cultivars, especially, are subject to attack. Often almost every seed-stem in the field starts dying at the base, and this proceeds gradually towards the seed-head. At the base of these infected seed-stems, clusters of sclerotia are usually evident. Such seed-stems are easily blown over and the seed yields are thus greatly reduced.

In the glasshouse, cold frame, hotbed, or in small increase-cages, where it is difficult to obtain good ventilation, neck-rot may be very destructive. The fungus infects the outer scales of the sheath region and gradually grows through the succeeding scales towards the centre of the plant. Later the seed-stalks are attacked and, when once infected, usually become completely girdled. The use of fungicides has never given satisfactory control. The best control has been obtained by keeping the foliage dry and providing good aeration. When mother bulbs are set in the glasshouse bench, they should be on raised beds in dry soil, and water should be applied only in the furrows, so that the tops of the beds remain dry. When bulbs are set in pots, they should be watered from below, by use of saucers, and the surface of the soil kept dry. In the spring, when the flower-stems are well developed, and the buds are breaking through the spathe, the leaves should be stripped, leaving the flower-stem bare to its base. This treatment can be given to breeding material growing in cold frames, hotbeds, glasshouses, and small increase-cages. It appears rather severe, but keeps the stems dry and prevents infection. The flowers open normally and good sets of seed are obtained.

SMUDGE (Causal Organism: *Colletotrichum circinans* (Berk.) Vogl.)

Smudge was first described by M. J. Berkeley in England in 1851. It is common in Europe, and in the central and northeastern United States. It is found to a lesser extent in other sections of the United States, having been widely distributed by onion sets. Smudge chiefly affects white cultivars. Although it causes some shrinkage in storage, it damages the crop primarily by marring the appearance of the bulbs and lowering their market value (Pl. 46(*a*)). Smudge is also found on shallots and leeks.

Onion smudge is confined to the neck and the scales of the bulb. It may be recognized by small green and black dots, often arranged in concentric rings, on the outer scales. It seldom attacks actively-growing parts of the plant. On coloured onions, the disease is confined to unpigmented portions of the outer scales of the neck; on fleshy scales it appears as sunken yellowish spots which enlarge slowly. In the presence of abundant moisture, the disease develops in the field at soil temperatures of 10° to 32°C., with an optimum of 26°C. Conidia are produced abundantly under moist conditions at temperatures of 20° to 30°C., and are disseminated chiefly by rain. Under suitable conditions, a conidial spore landing on an onion scale will germinate within a few hours. The fungus penetrates the cuticle of the outer epidermal wall, then the cell-wall, and finally the cell. Later, fruiting bodies are formed, which again produce conidia, the fungus passing through its whole life-cycle in a few days when the weather is warm and moist.

It has been known for a long time that coloured cultivars are more resistant to smudge than are white ones, and that certain antibiotics which are associated with the pigments in the outer dry scales act as a barrier to the organism. However, when the outer dry scales are removed, the organism can penetrate the fleshy scales of coloured and white cultivars with about equal facility. Infection is held to a minimum by using coloured cultivars that do not shed their scales. Pungent onions are more resistant to smudge than the mild types, especially under moist conditions. The difference in resistance is much greater between coloured and white cultivars than between mild and pungent ones, which indicates that the antibiotics associated with colour are more influential than the antibiotics associated with pungency (Owen *et al.*, 1950).

On white sets, the amount of smudge can be held to a minimum by curing under dry, well-ventilated conditions. If moist conditions prevail at the time of harvest, the sets should be dried by forcing hot air, up to 48°C., through shallow layers of sets in storage trays, then storing at about 0°C. and 65 per cent relative humidity with good ventilation.

To keep down field infestation, onion refuse from the warehouse should not be spread on new land. Crop rotation should also be helpful.

DAMPING-OFF (Causal Organisms: several)

Seed rotting, pre-emergence damping-off, and post-emergence damping-off of seedlings, causing thin or irregular stands, may occur whenever onions are grown from seed. Many different organisms, including *Pythium* spp. and *Pellicularia filamentosa* (Pat.) Rogers (*Rhizoctonia solani* Kuhn), have been listed as causing damping-off. Dusting the seeds, at the time of sowing, with Thiram (tetramethyl thiuram disulphide) dust at the rate of 4 oz. to 100 lb. of seed, is usually good insurance. Because of their susceptibility to damping-off, onion seedlings are much more difficult to grow in glasshouses than in the open. Chemical soil fumigants are now available for treating both the soil and containers in order to destroy the damping-off organisms before planting the seed. Care must be used in watering while the plants are small, especially during cloudy weather. On bright days water should be applied early in the morning, so that the soil surface will dry before night. After the first true leaf has appeared, there is much less danger of damping-off.

BACTERIAL DISEASES

BACTERIAL SOFT-ROT (Causal Organism: *Erwinia carotovora* (L.R.Jones) Holland)

This disease can cause considerable loss in storage. A number of different bacteria can cause rot, but *E. carotovora* is the one most often

(*a*) Thrashing onion seed with a combine The seed-heads are dry enough to thrash when the capsules and small seed-stems are sufficiently brittle to break readily when rolled in the palm of the hand Imperial Valley, California

Photos Desert Seed Co , Inc.

(*b*) Seed-to-seed production of the hybrid 'Granex' in the Imperial Valley of California, showing plants before the seed-stems have emerged The centre row is the pollen parent (*C line*) grown from mother bulbs, on either side are direct-seeded rows of the female plants (A line), sown about 6 weeks before the bulbs of the C line were planted. The 'male' and 'female' rows will flower simultaneously.

PLATE 42

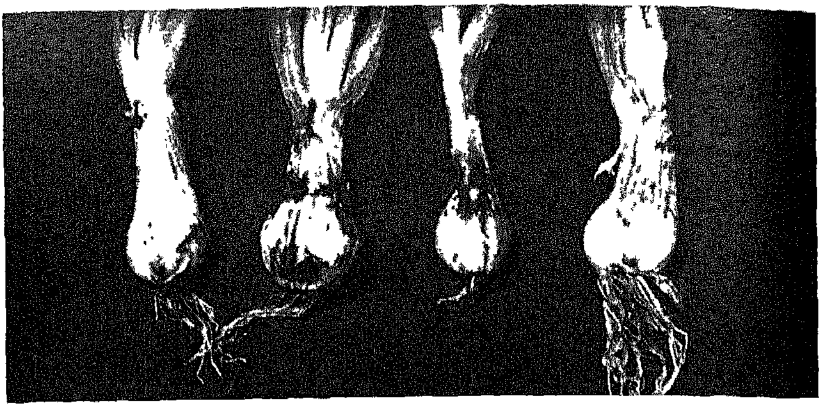


Photo Desert Seed Co., Inc.

(*a*) Smut lesions on onion plants. Mature spores are found in the conspicuous dark blisters. Onions are infected only in the seedling stage, and few plants survive as long as those shown here have done.

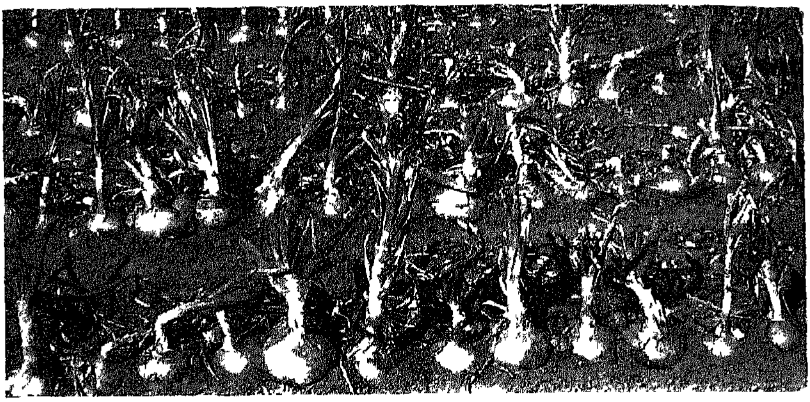


Photo A. M. Binkley

(*b*) Purple blotch on 'Sweet Spanish' onions, showing damage to the foliage. The foliage seems to be most susceptible as the plants are nearing maturity. Purple blotch causes losses both in the field and in storage.

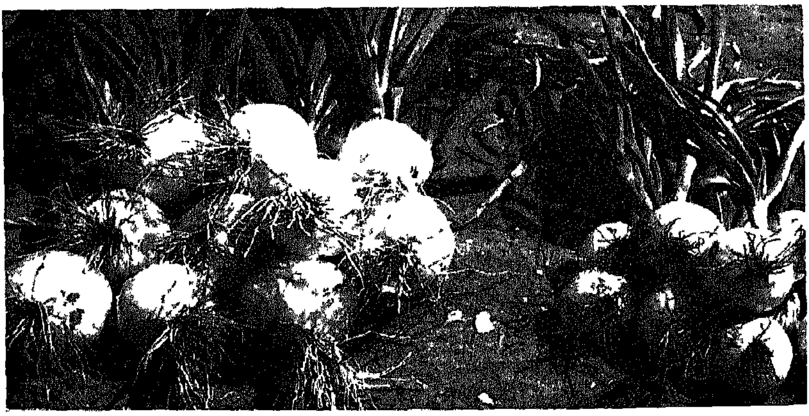


Photo E. W. Davis

(*c*) Pink-root on onions. *Left,* a pink-root-resistant strain of 'White Grano' grown in infected soil; *right,* susceptible bulbs of the same cultivar. Note the large bulbs and white, healthy roots of the resistant plants, and the small bulbs and poor roots of the susceptible plants.

PLATE 43

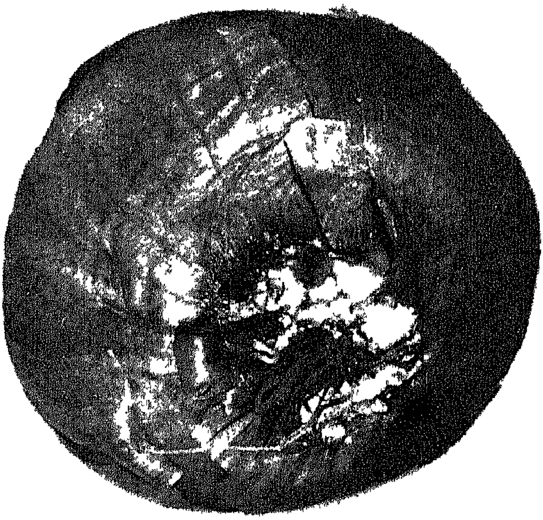


Photo U S Dep Agric

(*a*) Basal rot in 'Early Yellow Globe' in storage Tufts of mycelium are evident at the base of the bulb, all the scales are infected, and the bulb will gradually shrivel and 'mummify'

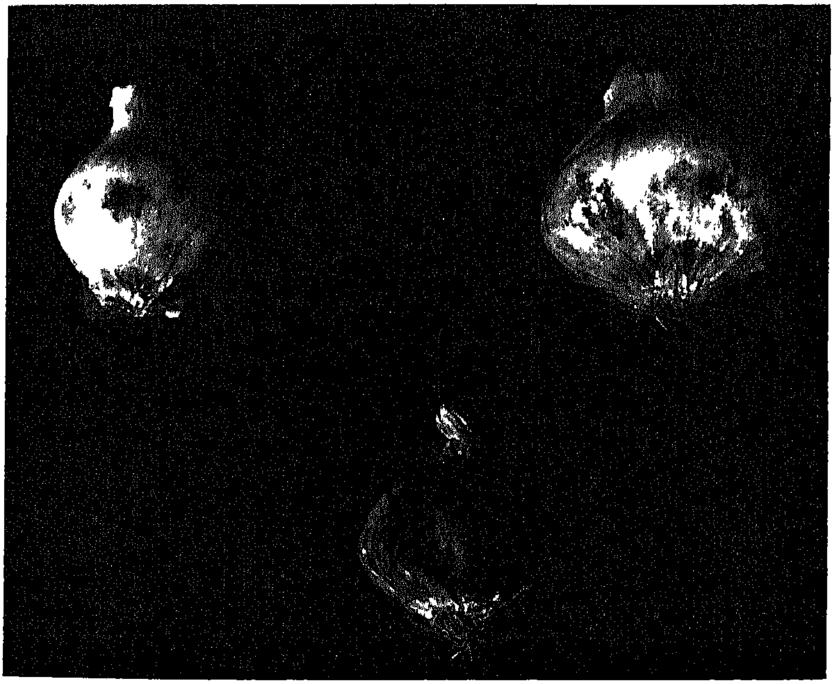


Photo Dessert Seed Co , Inc

(*b*) Black mould on 'White Creole' onions in storage Black, powdery masses of spores are borne on the outer scales or between them The spores can easily be rubbed off—in contrast to those of smut (Half natural size)

PLATE 44

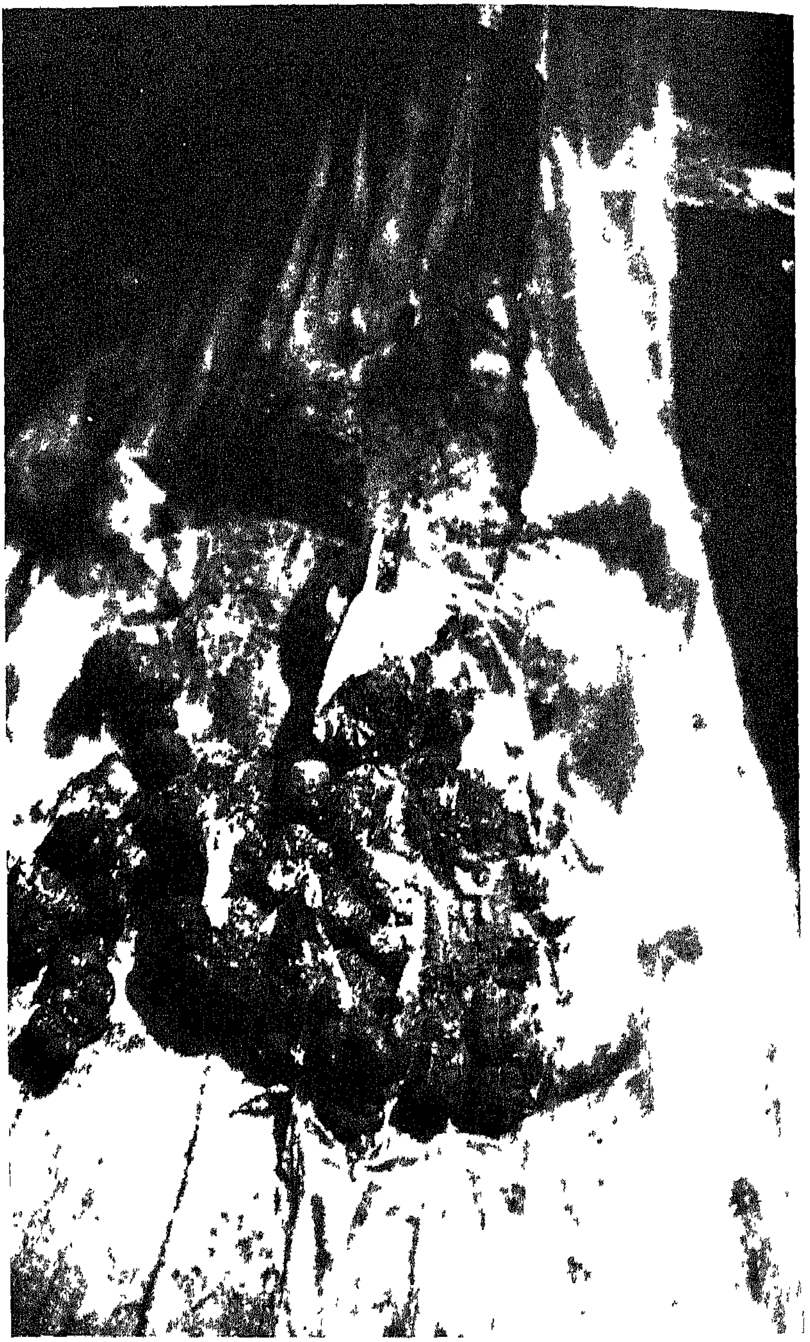


Photo Dessert Seed Co, Inc

Neck-rot An enlargement of part of the neck of an onion bulb showing sclerotia of the neck-rot fungus (*Botrytis* sp) These hard, kernel-like masses of sclerotia often occur in the neck region or other parts of the onion bulb in advanced stages of this disease

PLATE 45

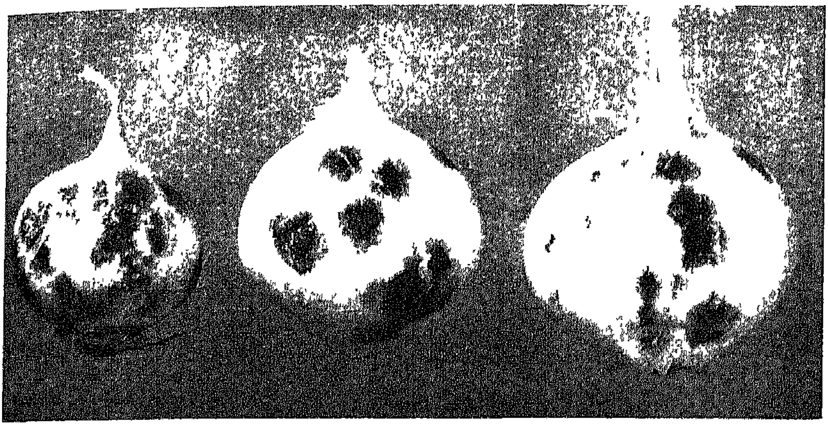


Photo U S Dep Agric

(*a*) Onion smudge on the cultivar White Portugal This disease is characterized by small green and black dots, often arranged in concentric rings, on the outer scales It is mainly harmful because it disfigures the bulbs and decreases their market value

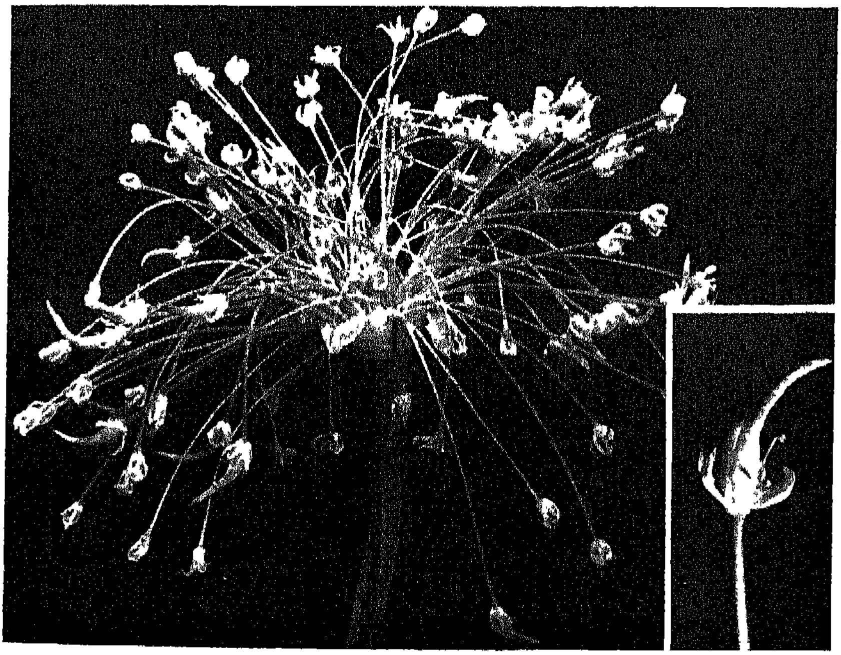


Photo W K Wahlert

(*b*) Onion flower-head infected with the aster yellows virus The pedicels are elongated and the floral parts distorted The inset shows a single flower with an abnormally developed pistil The infected flower-heads never produce seed

PLATE 46

Photo M. el Gammal

(*a*) Spraying for thrips control, Shandaweel, Egypt. In many countries, because of an abundance of labour, the hand sprayer and hand duster are the most economical means of applying insecticides.

Photo B. A. Perry

(*b*) For insect control, most large plantings of onions in the United States, whether grown for transplants, bulbs, or seed, are dusted or sprayed by aircraft. Insecticides can thus be applied quickly and efficiently, regardless of the condition of the soil.

Plate 47

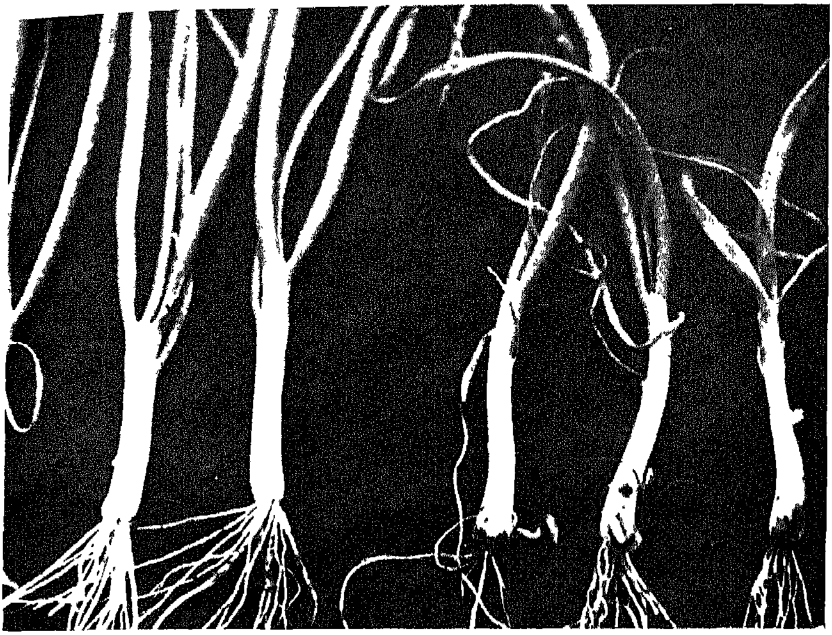


Photo Calif. Agric. Exp. Sta.

(*a*) The onion maggot. *Right*, maggots feeding on the bases of onion plants; *left*, unharmed seedlings. Onions at this stage of growth, or younger, usually die if attacked (G. N. Davis, 1957).

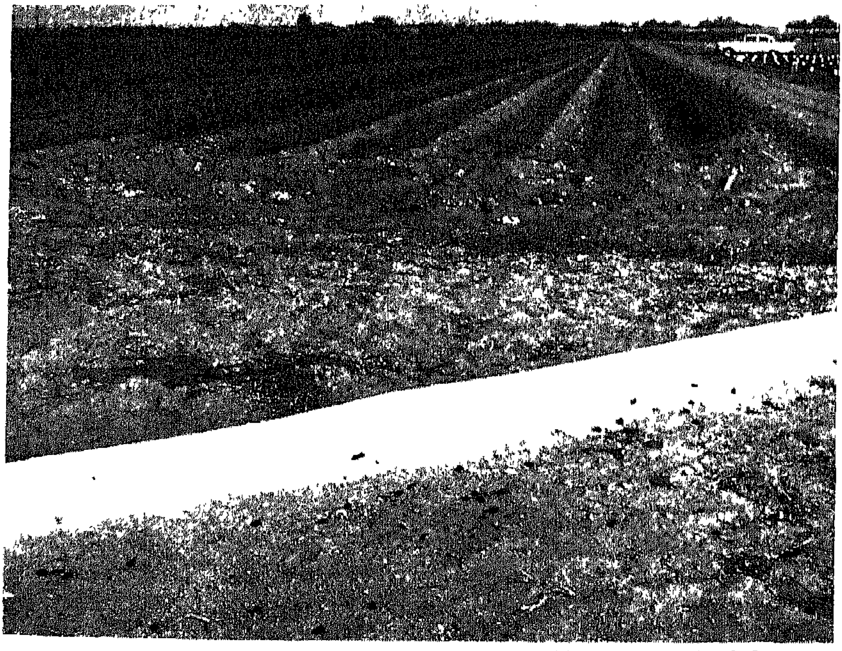
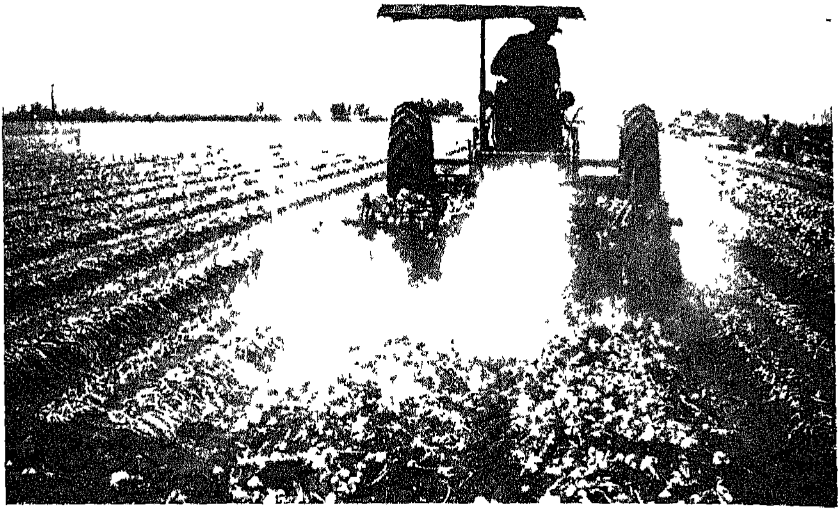


Photo Dessert Seed Co., Inc.

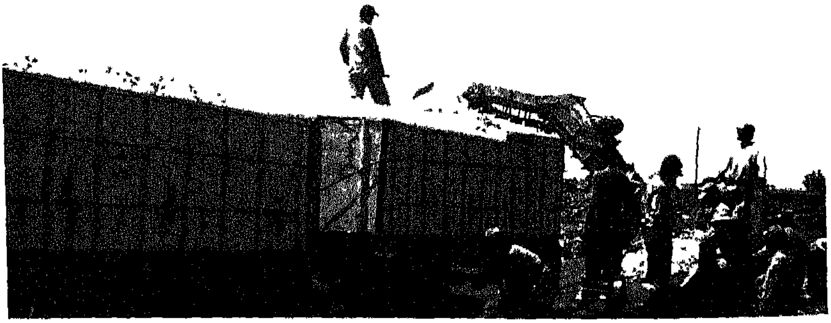
(*b*) Barriers of glassine or tin-foil are placed around the fields of young onions to protect them from the salt-marsh caterpillar. Insecticides are placed along the barrier to kill the caterpillars, or holes are dug in the soil to trap them. The barrier is about 6 in. high. Imperial Valley, California.

PLATE 48



(*a*) Harvesting 'White Creole' onions for dehydration Two beds are dug simultaneously, and the bulbs are spread on the soil surface Imperial Valley, California

(*b*) After digging, the 'White Creole' bulbs are picked up by hand, placed in baskets, and then emptied into burlap bags In the undug bed, left centre, there are four closely-spaced rows of bulbs on each side Following curing in bags, the bulbs are loaded into bulk carriers as shown in Pl 49(*c*) Imperial Valley, California



Photos Dessert Seed Co , Inc

(*c*) Loading 'White Creole' onions in the field, for transport to the dehydrator Imperial Valley, California

PLATE 49

cited. The rot usually begins at the neck of the bulb and affects one or more scales, but it does not spread rapidly from scale to scale. If only one or two inner scales are affected, the only external signs of the disease are a lack of firmness of the bulb and an offensive-smelling exudate that oozes through the neck when the onion is squeezed.

Soft-rot occurs most frequently in humid weather, especially in those cultivars that have heavy green necks and do not cure well. The moist neck tissue provides a good place for the rot organism to flourish. Soft-rot is especially bad during years of severe maggot infestation, as the maggots may carry the bacteria and inoculate the bulbs. Soft-rot may also follow damage from freezing. Thorough and rapid drying at harvest time is essential. All bulbs showing maggot injury should be discarded.

SOUR SKIN OR SLIPPERY SKIN (Causal Organism: *Pseudomonas cepacia* Burkh.)

This disease occasionally affects some of the outer fleshy scales of the bulb. The rot at first has a glazed appearance, then becomes slimy and yellow and gives off a characteristic vinegar-like odour.

VIRUS DISEASES

YELLOW DWARF

Yellow dwarf is world-wide in its distribution. It is not transmitted through the seed, and is especially severe on those onion types, such as shallots and potato onions, which are propagated vegetatively. Severe epidemics have been noted and reported when conditions for insect transmission have been favourable, when onion fields were located near onion dumps, when seed fields and mother bulbs were grown in adjacent fields, when crops for the production of dry sets and those from dry sets were grown side by side, and when mother bulbs that had been held over the summer for autumn planting had sprouted in storage. In this last case the sprouting bulbs were infested with aphids and, when they were planted in the autumn, the yellow-dwarf virus had spread to practically 100 per cent of the plants.

The initial symptom in plants that have been grown from naturally-infected onion bulbs is a series of short yellow streaks which appear at the base of the first leaf as it emerges through the neck of the bulb. Onion plants that have become inoculated in the leaves, either artificially with a needle or by insect vectors, show these first symptoms only at the base of the leaves that emerge after inoculation. Under conditions which are favourable for the development of yellow dwarf, all leaves that emerge after the appearance of the first symptoms show signs of the disease, but the leaves which had developed previously remain apparently healthy. Leaves showing the short yellow streaks at the base become yellow throughout, also crinkled and somewhat flat, and then lop over (Henderson, 1935). The flower-stalks show yellow streaks extending upwards from the base. Later these streaks coalesce, and the stalks become yellow throughout, and twisted and curled in a characteristic manner which gives the plants a decidedly dwarfed appearance. Infected sets produce small bulbs of little commercial value. Bulbs developed from onion plants on which only the last few leaves show symptoms, or from plants with completely masked symptoms, are usually normal in development and appearance. The flower clusters of infected mother plants are smaller, and have fewer flowers, than those of normal plants.

Several species of aphids serve as vectors of yellow dwarf. The virus can also be transmitted mechanically. Strains of yellow-dwarf virus, varying from mild to severe, have been isolated from onion and shallot.

In eastern Iowa, onions that were being grown for dry sets became infected when grown near seed fields or near onions that were grown for large bulbs. The percentage of diseased plants in the bulb crop was greatly reduced when dry sets were grown in separate districts that were free from yellow dwarf, and when volunteer plants were destroyed (Henderson, 1935). Onions that are planted for seed or bulbs near onion dumps, usually show a high incidence of yellow dwarf; cleaning up these dumps helps to bring the disease under control. Where sprouting is likely to occur under warm storage conditions, mother bulbs should be dusted with an aphicide when put into storage. The tree onion is a symptomless carrier of the yellow-dwarf virus, and probably should not be grown near other onion plantings (Brierley & Smith, 1944). 'Sweet Spanish', 'Grano', and Bermuda-type onions, are resistant to the common strain of yellow dwarf.

ASTER YELLOWS

In the United States, aster yellows affects many wild and cultivated plants such as carrot, celery, lettuce, onions, shallot, and asters. The disease is carried by the six-spotted leafhopper (*Macrosteles facifrons* Stål.). If infected bulbs are placed in storage, they usually sprout prematurely and become badly shrunken, but bulbs from late-infected plants may not show the disease until they are planted and the foliage has developed. The leaves of systemically infected plants are distinctly light-yellow, but often only one branch of the plant will show symptoms. Infected plants produce long pedicels, the flower parts are distorted, and the flowers are sterile (Pl. 46(*b*)). Usually, only a small percentage of the plants in a field is infected.

Control measures have not been developed, but where aster yellows is prevalent, onions should not be planted adjacent to fields of lettuce, celery, carrots, or other crops which are especially susceptible to the disease.

INJURY FROM OTHER CAUSES

CHEMICAL INJURY

A post-harvest injury that occurs occasionally is 'alkali scorch' or 'bag print'. Dark-brown or black spots sometimes appear where yellow or red onions come into contact with alkali-impregnated jute-bag containers, although not all bags produce this discoloration.

A chemical injury which is occasionally found in onions that have been in cold storage is caused by ammonia fumes, small amounts of which will cause marked discoloration. The fumes alkalinize the outer pigmented scales and produce colour changes that make the bulbs unattractive. Yellow onions show brown blotches or a uniform brown colour over the exposed surfaces, red onions change to a deep greenish-black, and white onions become greenish-yellow. The extent of injury varies with the strength of the chemical, the percentage humidity, the length of exposure, etc.

SUNSCALD

If temperatures are high, sunscald may occur before harvest; but it is commoner after harvest, while the onions are curing in the windrow. The tissues that are exposed to the direct rays of the sun are killed and become soft and slippery. The injured areas then lose moisture by evaporation and become sunken, leather-like, and usually almost white. Keeping the bulbs covered with soil before harvest, and protecting them from the sun after harvest, will prevent sunscald.

Exposure to light often causes greening, especially in white onions, but otherwise does not cause injury. This green may partially disappear in dark storage or while the bulbs are being shipped to market.

FREEZING

Onion bulbs vary in the temperature at which they will freeze. Most cultivars can be cooled to about −2° C. without injury. When freezing injury occurs, the fleshy scales have a watersoaked appearance after thawing. Frozen onions show less damage if thawed at about 4° C. than if thawed at higher temperatures. Freezing injury may be increased if bulbs are jarred while super-cooled or frozen. Among cultivars, there are considerable differences in the amount of cold which the growing crop will tolerate; as a rule, those cultivars which are low in solids, such as the Grano types, are the least tolerant.

BLAST

This disease is prevalent in the Connecticut Valley of Massachusetts and in Orange County, New York, and has been reported from time to time elsewhere. When succulent foliage that has developed during warm, moist growing periods is subjected to direct sunshine, high temperatures, and low humidity, a rapid dying of the foliage occurs, starting at the leaf tips. In certain districts, a member of the fungus genus *Botrytis* has been found associated with blast, and control has been obtained by use of Maneb (manganous ethylene bisdithiocarbamate) spray. McLean & Sleeth (1959) report a tip- and leaf-blight of the onion in the Lower Rio Grande Valley of Texas as caused by *Botrytis squamosa* J.C.Walker. Recurrent periods of excessive rain, high humidity, and cool, cloudy weather, favour the development and spread of the disease. Early symptoms are a light scorching of the tips of older leaves, which turn tan-coloured or light-brown and die. Later on the infected leaves collapse. The disease is especially severe in young, thickly planted onions. The foliage of the short-day red cultivar Tropicana seems to be highly resistant to the type of blast caused by *B. squamosa*.

XVI

INSECTS, MITES, AND NEMATODES, AND THEIR CONTROL

As the insecticides mentioned in this chapter are extremely poisonous to humans, livestock, and beneficial insects, they must be used with great caution. For this reason, in some countries legislation has been enacted that prohibits the use of certain chemicals and establishes tolerances for others. Because of the many laws and regulations that exist, local agricultural specialists and law-enforcement agencies should be consulted before chemicals are used. Directions on the container should be carefully followed, not only to get the best results, but also to understand the precautions that are necessary for safe handling. Insect control presents a constantly changing picture: resistant strains of insects develop; controls that are effective in one area are not effective in another; phytotoxicity affects seed germination and retards plant growth; and new insecticides are continually appearing. For such reasons as these, it is advisable to keep up-to-date by consulting specialists regarding chemicals to use, methods of application, and regulatory measures.

Wherever possible, widely accepted common names of pesticides have been used in this chapter. Some pesticides have only proprietary names, and these are so indicated. For purposes of identification, the chemical names of the active ingredients of the pesticides are given in Appendix I.

Growers who are producing onion bulbs or onion seed must be constantly on the alert to protect their crops from a number of destructive pests. The two insects which do the most damage are onion thrips (*Thrips tabaci* Lind.) and the onion maggot (*Hylemya antiqua* Meig.). The former has world-wide distribution and causes some injury almost everywhere; the latter is less widely distributed, and its attacks are often sporadic. Because of the large amount of damage which is done by these two insects, they will be discussed in some detail. Other pests that attack onions, such as the seed-corn maggot (*Hylemya cilicrura* (Rondani)), the salt-marsh caterpillar (*Estigmene acrea* (Drury)), various species of wireworms of the genus *Limonius*, cutworms of the family Noctuidae (such as the black cutworm, *Agrotis ipsilon* (Hafnagel), and the variegated cutworm, *Peridroma saucia* (Hübner)), the pea leafminer (*Liriomyza langei* Frick), and several species of mites, will be discussed briefly. Besides insects and mites, the stem and bulb nematode, *Ditylenchus dipsaci* (Kühn) Filipjev, is widely distributed and causes considerable damage; and the stubby-root nematode is reported to damage onions in the Lake Labish district of western Oregon.

THRIPS

Considered on a world-wide basis, the onion thrips probably does more damage to onions and their allies than do all the other animal pests combined. Haeussler (1952) estimated that losses from this pest in 1944 in the United States alone amounted to $14,500,000. Although improved methods of control have been developed since 1944, this thrips continues to be onion animal enemy number one. The severity of thrips attack may vary from year to year, depending largely upon climatic conditions, but it is usually greatest when rainfall is below, and temperatures are above, normal.

The egg, larval, and adult stages are found on the plant, but pupation occurs in the soil. The adults are 1·0 to 1·2 mm. long and usually light-brown in colour. They have two pairs of fringed wings and are able to fly considerable distances to onion fields from other host plants. The female usually lays her eggs on the tender tissues of the protected inner leaves, where they hatch in from 4 to 10 days, depending upon the temperature. The white or very pale yellow larvae may readily be seen by separating the inner leaves, where they feed and are shielded from the weather and insect predators. The growing larvae moult twice in the 5-day period that is usually required from hatching to their attainment of maturity. They then enter the soil to pupate, and the adults emerge in about another 4 days. The average life-duration of an adult female is 2 to 3 weeks. As many as ten generations a year may be completed in areas where the climate is favourable throughout the year.

Both the larvae and the adults cause injury. They feed by rasping the surface of the leaves and sucking the liberated juices. Badly damaged foliage may give the entire field a silvery appearance, yields may be greatly reduced, and keeping quality impaired. Usually a few thrips are carried into storage on mother bulbs, and when these mother bulbs are planted in the spring, the over-wintering thrips soon become active. In warm climates, thrips feed on the foliage of sprouted bulbs in storage, and increase rapidly in numbers unless the bulbs are protected with an insecticide. On the seed crop the thrips accumulate and feed on the inflorescence; they injure the young florets and, when abundant, cause a poor set of light seed. The thrips population in the inflorescence can be estimated by giving it a sharp blow, so that the dislodged thrips fall into the palm of the hand.

As regards control, climatic conditions may help to hold thrips in check, as cool temperatures slow up their activities and reduce the number of generations, and moreover, driving rains frequently destroy them in large numbers. Certain insect predators, such as the spotted and convergent ladybird beetles and the larvae of the syrphid fly, may also help to control thrips. Whenever possible, preventive measures should be used to restrict the thrips population. The cutting and burning of grass and weeds in waste places will destroy alternate hosts and places for hibernation, and deep ploughing will bury refuse that harbours thrips. Set onions or bunch onions should not be planted adjacent to fields that are to be seeded to onions later.

To get the necessary control, preventive measures usually need to be supplemented by the application of insecticides in the form of dusts or sprays. These are applied by hand (Pl. 47(*a*)), by power ground equipment, or by airplane (Pl. 47(*b*)). For the bulb crop Wilcox & Shirck (1958), of the U.S. Department of Agriculture, recommend one of the following, either as a dust or as a spray: DDT, Toxaphene, Malathion, Heptachlor, Dieldrin, or Parathion. Either emulsifiable concentrates or wettable powders are used in high-gallonage sprayers, and emulsifiable concentrates are employed in mist blowers or low-gallonage sprayers. The recommended amounts of insecticide to be used, and proper dilutions for high-gallonage, low-gallonage, or mist sprayers, are usually given on the labels of the marketed product, or may be obtained from official agencies. Application of both sprays and dusts by airplane is becoming increasingly common; in onion seed fields, ground equipment cannot be used to advantage after the seed-stems have elongated.

DDT, Parathion, Toxaphene, Heptachlor, or Dieldrin, should not be applied to onions that are to be eaten green; only Malathion should be so used, and it should not be applied within 3 days of harvest. Parathion should not be applied to bulb onions within 15 days of harvest, nor Dieldrin within 14 days, nor Heptachlor within 5 days. For the seed crop, any of the insecticides mentioned above may be applied until the plants start to flower, but then only DDT or Toxaphene should be used. These should be applied late in the evening, to minimize injury to pollinating insects, and at weekly intervals as long as proves necessary.

H. A. Jones *et al.* (1934) found that damage from thrips was more pronounced on some cultivars than on others. White Persian, Japanese bunching onion, Grano, Sweet Spanish, Crystal Wax, and Yellow Bermuda, all had a much smaller thrips population than Australian Brown, Ebenezer, and the Yellow Globe types.

ONION MAGGOT

The onion maggot (*Hylemya antiqua* Meig.) is present in Egypt, Israel, the British Isles, northern Europe, Canada, and the onion districts of the northern United States. In certain localities, damage may vary from year to year; in other districts the crop is continually threatened with heavy losses, so that growers must always be on the offensive to keep this insect under control.

The adult male fly is somewhat smaller than the house-fly. Its body is a light greenish-grey, and the colour of the female is similar, but lighter and less distinctly marked. As a rule, the life of the male is shorter than that of the female. Under field conditions, male flies may live for as long as 10 days; females may live 25 days. When they were hatched in the laboratory, Eyer (1922) found the ratio of male to female flies to be about 1 : 1; when they were trapped in the field, the ratio was about 1 : 3.

The eggs are laid on the lower part of the onion plant, or in crevices in the soil near the plant. Late in the season the female may deposit eggs directly on the bulbs. The egg is white, 1·2 mm. long and 0·5 mm. wide, slightly flattened at one end and bluntly rounded at the other. The female usually lays 30 to 40 eggs, and the incubation period is 2 to 7 days, depending upon the temperature. On hatching, the larvae are translucent-white and about 1·0 mm. long; they continue to feed until they are about 10 mm. long. The larval stage lasts from 15 to 25 days; high temperature and high moisture conditions shorten the larval stage, but low temperature and low moisture conditions will lengthen it.

The puparium is elongate-ovate and bluntly rounded at the ends; it varies in colour from light yellowish-brown to deep reddish-brown, and resembles a kernel of wheat. Over-wintering puparia are almost black and vary in size, depending upon food conditions; but the average length is usually 4 to 5 mm. The pupation period lasts from 7 to 14 days, depending upon the temperature. Over-wintering is mostly as pupae; these may be found in cull onions or buried several inches deep in the soil.

The maggot feeds upon onion plants of all ages, from young seedlings to mature bulbs (Pl. 48(*a*)). Thus larvae may proceed down a row of seedlings, destroying them and leaving wide skips in the stand; if the infestation is bad, they may almost totally destroy the crop. Maggots may do considerable damage in fields that are planted for dry sets, by thinning the stand and causing over-size sets to be developed. They channelize mature bulbs, thus permitting bulb-rotting organisms to enter.

Where maggots are a problem, sanitation practised on a community-wide basis is necessary, regardless of other methods used for control. Infected cull onions from storage houses and packing sheds should be hauled to dump piles and covered with at least 1 ft of soil in early spring before the adult flies emerge. These burial places should then be dusted several times, at 10-day intervals, with 10 per cent DDT—to kill any adults that get to the surface. Fields that have been under onions should be disked to destroy the bulbs and then ploughed to bury deeply the refuse harbouring the maggots and pupae. Where onions have been fed to livestock in feeding yards, the debris should be removed as completely as possible and buried. If onions have been trampled into the soil, the area should be ploughed deeply and the surface dusted with DDT as recommended above. Early in the spring, before the seedlings emerge, ditch banks and fence rows surrounding the fields, should be burned and sprayed to destroy the adult flies before they can lay their

Granular chemicals such as Ethion, Trithion, and VC-13 (the last two being proprietary products), are used for control in some districts. When applied in the drill row at the time of seeding, a single application may protect the onion plants throughout the season. Tozloski (1954) obtained good control in plantings for dry sets by mixing the dry seed with powdered insecticide at the time of planting.

Very little difference has been found between cultivars of *Allium cepa* in their resistance to onion maggot, but Perron *et al.* (1958), working in Canada, found that the cultivars of *A. fistulosum* were more resistant than those of *A. cepa.*

SEED-CORN MAGGOT

While the onion maggot will attack the onion plant at all stages of growth, the seed-corn maggot (*Hylemya cilicrura* (Rondani)) attacks only the germinating seed and the very young seedling. The adults look like small house-flies, being light-grey in colour and about 5 mm. long. The eggs are deposited in the soil on decaying organic matter, and the small white maggots hatch in 2 to 3 days and feed on the sprouting seed. Where these maggots occur, soils that have a large amount of decaying organic matter should be avoided, organic fertilizers should not be applied in the row, and conditions should be provided that stimulate rapid germination.

Control has been obtained by treating the seed with Lindane, Aldrin, Dieldrin, or Heptachlor. Soil applications of Aldrin, Dieldrin, or Heptachlor, as the plants emerge, may be necessary with severe seed-corn maggot infestations.

SALT-MARSH CATERPILLAR

The salt-marsh caterpillar (*Estigmene acrea* (Drury)) is widely distributed and may do considerable damage to crops. It over-winters as a mature caterpillar, pupation takes place in early spring, and adult moths appear in late spring and in summer. The female moth is white with an orange abdomen, and has black spots on the wings and abdomen. The hind wings of the male are orange instead of white. The white, somewhat flattened eggs are laid in masses on a variety of plants. The young larvae are hairy and grey, and are not difficult to kill with poison sprays and dusts; but they become increasingly resistant as they grow older. The mature hairy caterpillars are about 50 mm. long, with black and yellow bands. When they suddenly lose their food supply, they migrate in large numbers across roads and highways in search of new vegetation. A typical migration occurs in the autumn when cotton fields are sprayed with defoliants. When this migration occurs in districts such as the Imperial Valley of California, it is necessary to erect barriers of glassine or tin-foil to protect the growing crops (Pl. 48(*b*)). A band of insecticide dust, spread along the barrier, destroys the caterpillars.

WIREWORMS

Attacks by wireworms (*Limonius* spp.) are often very serious, especially if onions are sown on newly broken sod. The wireworm is the larval stage of the click beetle; it is hard-shelled, yellow or brown in colour, and 12 to 40 mm. long. The span of the life-cycle is 2 to 5 years, depending upon the species. Damage is done by the larvae feeding on the underground parts of the onion plant; they either kill the young seedlings, reducing the stand, or tunnel into the bulbs, making them subject to rot and thus unfit for sale.

For chemical control of wireworms on muck soil, Harmer & Lucas (1955) recommend the application of 12 lb. per acre of 25 per cent wettable Aldrin powder. This is used as an aqueous spray and disked into the soil before the seed is sown. For the control of the Pacific Coast wireworm on irrigated land, the soil is treated with 10 lb. of DDT per acre after harvest in the summer or autumn, or before planting in the spring (Anon., 1952). The DDT is sprayed or dusted on the soil surface and thoroughly mixed in the soil to a depth of 6 to 9 in. The wireworms are killed within 6 to 8 weeks after application, but the chemical remains in the soil and prevents new infestation for several years.

CUTWORMS

Cutworms are the larval stage of moths (family Noctuidae) of various colours and markings which depend upon the species. The caterpillars are smooth, cylindrical, dull in colour, and variously marked. They cause damage mostly by cutting off the young onion plants at the surface of the soil. Cutworms feed at night and hide in the soil or trash near the plants during the day. They can usually be found by digging into the surface soil in the vicinity of a freshly cut plant.

Control is obtained chiefly with poison baits. One bait that is often recommended is made by thoroughly mixing 1 lb. of sodium fluosilicate with 25 lb. of wheat bran and moistening the mixture with water. The bait is mixed in the morning and applied in the evening, so that it will be moist and attractive when the cutworms start to feed. Paris green (copper aceto arsenite) can be substituted for the sodium fluosilicate. The bait can be placed around the plants or distributed uniformly over the field. Dusting in late evening or at night with 10 per cent Toxaphene, 5 per cent DDT, 5 per cent Chlordane, 2·5 per cent Aldrin, or 1·5 per cent Dieldrin, is often effective. Sprays containing an equivalent amount of these chemicals may also be used.

SPIDER MITES

In the western United States the most destructive spider mites on both the bulb and seed crop of onions are the common red spiders—tiny mites that are difficult to see without magnification. These mites (*Tetranychus* spp.) feed on a wide range of host plants, both wild and cultivated, and are most abundant when the weather is hot and dry. The average length of the orange or reddish female is about 0·42 mm. The eggs are globular and pale-yellow, and the young mites are yellowish. On the onion bulb crop, red spiders are found mostly on the undersurfaces of the leaves. They suck juice from the epidermal cells, giving the leaves a bleached appearance. If they are not checked, a delicate web may be spun over most of the plant; and if they are not controlled in seed fields, the spiders spin a fine web over the inflorescence, which prevents visitation by pollinating insects. The flowers and developing seed-capsules are injured, and seed yields may be greatly reduced. In warm climates the red spider over-winters in refuse and on green vegetation; in cold climates, over-wintering is chiefly by adults in the soil.

Control is obtained by destroying weeds, either by cutting or with herbicides; driving rains may check a severe infestation, and overhead irrigation is also effective. Kelthane, a proprietary product, should be used in accordance with the directions on the container.

OTHER INSECT AND MITE PESTS

In the southwestern United States, the brown wheat-mite (*Petrobia latens* (Müller)) may become destructive on the onion seed crop. This mite is dark reddish-brown in colour, is fairly large, and is easily identified. Centres of infection in the field become yellowish. If mites alone are a problem, control can be obtained by the use of 98 per cent dusting sulphur applied at the rate of 25 to 30 lb. per acre when the maximum temperatures are 90°F. or above. At lower temperatures, Parathion effects control. If both thrips and mites are a problem, then an insecticide should be mixed with the sulphur.

The onion-bulb mite (*Rhizoglyphus echinopus* Fumouze & Robin), which attacks the bulbs of tulips and other plants, is a serious pest on onion bulbs in storage.

Small leaf-mining flies of the genus *Liriomyza* attack onions and a whole range of other crop plants in many parts of the world. The pea leaf-miner (*Liriomyza langei* Frick) is reported as attacking the onion bulb crop in western Oregon (Crowell *et al.*, 1961) and causing damage to the crop in California. The tiny, adult female fly punctures the leaf tissue with her ovipositor and inserts eggs singly into the wounds. The larvae soon hatch and feed on the tissue under the epidermis, forming a blotch-type pattern. When the larvae are present in large numbers, the mines overlap, girdling the leaf, and causing wilting of the leaves and reduction in the yield of bulbs. The mature larvae cut an opening in the epidermis and crawl out of the leaf to pupate in the soil. Occasionally pupation occurs in or on the leaves. Several generations develop during a season. Besides onions, the leaf-miner is reported to attack peas, beets, spinach, celery, cauliflower, lettuce, petunia, and aster.

Tiny wasp parasites help to hold the insect under control, while a Parathion spray is reported to effect good control of the adult flies.

NEMATODES

STEM AND BULB NEMATODE

The onion strain of the stem and bulb nematode (*Ditylenchus dipsaci* (Kühn) Filipjev) is a tiny, worm-like organism that is barely visible to the naked eye. In the United States it has been reported as occurring on onions and garlic; in the Netherlands on onions and chives; and in England and Brazil on onions. When onions are grown on infested soil, emergence of the seedlings is somewhat retarded. Infected plants become pale and thickened, and of various abnormal shapes by the time they are ½ in. high. Splitting of the epidermis occurs on the enlarged parts of the seedling. On onions that are grown from sets planted in the field, the first symptoms are stunting of the plants, flaccidity of many outer leaves, die-back of outer leaf tips, and drooping of leaves. When the bulbs swell, the nemas move down the leaves to the outer scales of the bulb, causing the tissue beneath the outer scales to become soft and mealy. This lace-like mealiness, which looks like thick frost, becomes more pronounced as the season advances. During storage, activity of the nemas continues, and bulbs become lighter in weight and somewhat puffy (Newhall & Chitwood, 1940).

When the plants die, the nemas remain in the dead tissue or enter the soil and attack a new host. They can remain in a dormant condition for long periods. Dead plant tissues harbouring nemas in a dormant state are probably an important source of infestation. This nematode may also be widely disseminated by infected dry sets. In England, nemas have been found in the inflorescence and on seed produced from such heads. Consequently, onions for seed should not be grown on nematode-infested land (Anon., 1956). Garlic, which is propagated vegetatively, is one of the chief disseminators of this pest. For notes on this and other host plants and on control, *see* Chapter XVIII, pp. 224–5.

STUBBY-ROOT NEMATODE

Jensen & Konicek (1961) report that a nematode, probably closely related to *Trichodorus christiei* Allen, attacks onion roots in the Lake Labish district of western Oregon. Losses in this district, resulting from a reduction in the size of the affected onions, are estimated at 10 to 12 per cent. Stunted onions occur in patches which reappear each year in approximately the same place. The stunting is most evident early in the season and becomes less apparent late in the summer. Affected onions have only a few short roots, which are yellowish in colour and have dark-brown tips and numerous localized lesions. During the growing-season, the nematode inhabits the upper 6 in. of soil, but little is known about its life-history, host-range, or methods of control.

Hoff & Mai (1962) report on damage caused by *T. christiei* to the onion bulb crop in the muck soils of New York State. In pot experiments they found that Telone (proprietary name) gave good control when applied at the rate of 40 gal. per acre.

XVII

ONION PRODUCTS

THE expanding demand for onion products, which has been evident for some years, seems likely to continue. The greatest demand is for dehydrated products. These are used mostly for seasoning—in canned meat products, sausages, canned soups, dried soup mixes, chili con carne, chili sauce, and catsup. Dehydrated soup is one of the most popular items, and increasing amounts of dehydrated onions are being used in salads. Quantities of French-fried and chopped onions are processed by the frozen-food industry, and pickled onions of many kinds are found on grocery shelves. Although onions have not been canned to any great extent, there is a growing interest in this item.

DEHYDRATED ONIONS

Dehydrated onions are becoming a product of considerable importance in world trade. The United States, leading all other countries in the quantity of onions which she dehydrates, produced at the beginning of World War II about 1,000,000 lb. annually of the dehydrated product; but by 1946 the amount had risen to about 12,000,000 lb. annually. In 1947, production dropped sharply to about 2,000,000 lb., but then it rose again, so that in 1961 the total production was in excess of 20,000,000 lb. In addition, considerable quantities of dehydrated onions are imported into the United States from other countries; in 1960 this amounted to over 1,265,000 lb. (Table XXIX).

In recent years, Egypt has gradually increased her exports of dehydrated onions (Table XXX), until in 1960 these amounted to 5,578 tonnes, most of which went to West Germany, the Netherlands, Switzerland, the United Kingdom, and the United States. Egypt began dehydrating onions in 1938, as a means of conserving shipping space during World War II. At first the dehydration plants were located at the ports of export, Alexandria and Port Said, but additional facilities have now been built in the onion producing districts of Middle and Upper Egypt. Some of the other countries which produce and export dehydrated onions are indicated in Table XXIX.

Advantages which are claimed for dehydrated onions are the reduction of transportation costs and the avoidance of losses of bulbs in storage. In addition, dehydrated onions are more uniform in flavour than are

TABLE XXIX

IMPORTS OF DEHYDRATED ONIONS INTO THE UNITED STATES, BY COUNTRY OF ORIGIN, 1956–60

(Data from Bureau of Census work sheets, U.S. Department of Commerce)

Country of origin	1956 (lb.)	1957 (lb.)	1958 (lb.)	1959 (lb.)	1960 (lb.)
Bulgaria	0	2,222	11,023	420,338	501,850
Egypt, U.A.R.	396,420	407,081	284,758	152,368	282,437
Hungary	0	0	0	16,500	160,764
Netherlands	0	53,464	259,092	188,381	104,123
Mexico	0	0	0	0	61,340
Germany, West	0	0	22,422	10,470	46,184
Turkey	14,360	0	22,046	230,108	43,693
Yugoslavia	0	0	0	0	26,473
Poland	0	0	0	0	22,054
South Africa (Republic of)	0	0	0	0	8,535
Israel	0	0	0	0	4,409
Morocco	0	0	0	0	2,240
France	1,270	0	3,672	4,200	1,026
Italy	0	33,599	32,000	4,220	335
Libya	0	2,206	0	0	0
Lebanon	0	48,880	51,200	0	0
Switzerland	0	11,023	0	0	0
Argentina	0	0	1,080	0	0
Total	412,050	558,475	687,293	1,026,585	1,265,463

TABLE XXX

EXPORTS OF DEHYDRATED ONIONS FROM EGYPT, 1951–60. EACH YEAR EXTENDS FROM MARCH 1ST TO THE END OF FEBRUARY

(Agence Internationale de Statistiques, Alexandria, Egypt)

Year	Tonnes	Year	Tonnes
1951–52	1,778	1956–57	3,364
1952–53	1,329	1957–58	3,500
1953–54	2,264	1958–59	2,944
1954–55	2,592	1959–60	5,578
1955–56	2,487		

fresh ones. In many processed products, identifiable pieces of onion are desirable; this is more easily attained with dehydrated than with fresh onions.

The best onions for dehydration have small necks and small root zones, are high in pungency, and do not discolour or develop a bitter flavour on drying. They should be of similar composition throughout, so that all slices will dry at a uniform rate. Such onions must also store well, be free from diseases and mechanical injury, and above all be high in their content of total solids. Onion bulbs vary in dry-matter content from as low as 4 per cent in some mild types to about 25 per cent in those that are highly pungent. Even within a cultivar, individual bulbs may vary considerably in their content of solids. Mann & Hoyle (1945) showed how the refractometer can be used to select bulbs with high dry-matter contents which can then be used in breeding to improve the cultivars that are used for dehydration.

In the United States, onion bulbs for dehydration are grown in several of the western states, but most of the processing is done in California. White cultivars are used almost exclusively, the most popular being White Creole and Southport White Globe. The processing season extends from April through November. 'White Creole' is grown chiefly as a winter crop in the southern areas of production, and 'Southport White Globe' as a summer crop farther north. The development of early-maturing hybrids has made it practicable to process over a longer period than was formerly possible.

In the southwestern United States, 'White Creole' bulbs for dehydration are grown chiefly under irrigation. Seed is sown on raised beds, usually 4 to 8 rows to the bed (Pl. 49(*a*)). The seed is usually precision-planted to avoid crowding. As a rule, harvesting is delayed until the tops have fallen. In topping, power-operated equipment sucks the tops into an upright position, and either a rotobeater or a revolving blade chops the leaves into fine pieces and scatters them over the soil surface so that they will not interfere with harvesting. If bulbs are not to be lifted for some time, they are covered with soil to prevent greening. Bulbs are dug with a modified potato digger which lifts them from the soil, carries them on an endless steel belt that sifts out the soil, and drops them behind the digger (Pl. 49(*a*)). They are immediately placed in baskets by hand and then emptied into burlap bags where they remain until they are hauled to the plant (Pl. 49(*b*)). While the trucks are being loaded in the field (Pl. 49(*c*)), the onions are run over a grader which sifts out the small bulbs and debris; at the same time the diseased, injured, and off-coloured bulbs, are sorted out by hand.

'Southport White Globe' for dehydration is grown in central and northern California, Nevada, southwestern Idaho, and eastern Oregon. In these areas, rainfall must be supplemented by irrigation. On the peat lands of the California delta region, the crop may be sub-irrigated, but overhead sprinklers are widely used. In other locations, irrigation water is applied in furrows between raised beds on which the onions are planted in either single or double rows. Harvesting and curing practices are about the same as those used for 'White Creole'. Harvesting usually starts in the southern districts in July and continues into the higher altitudes and latitudes as the season progresses—usually into October.

Following harvest, the onions are transported from the field to the processing plant, where they are unloaded mechanically and stored until they are processed. The actual storage period varies: if the onions

PLATE 50

Bulb development in garlic in relation to storage temperature of planting stock. Storage temperature, top to bottom: 0°, 5°, 10°, 15°, and 20 C The bulbs were grown from a planting on April 29th, after 9 months of storage. The lots stored at 0 and 5°C received so much low temperature that they have become rough; those stored at 15° and 20 C did not receive sufficient low temperature to form bulbs. The largest bulbs are 1½ to 2 in in diameter (Mann & Minges, 1958)

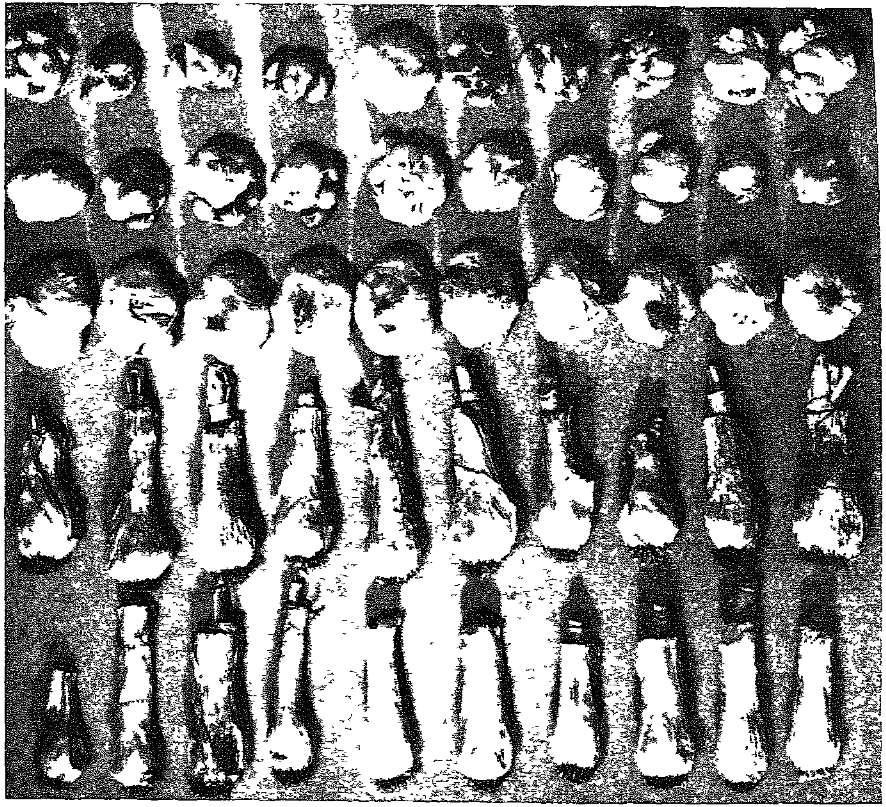
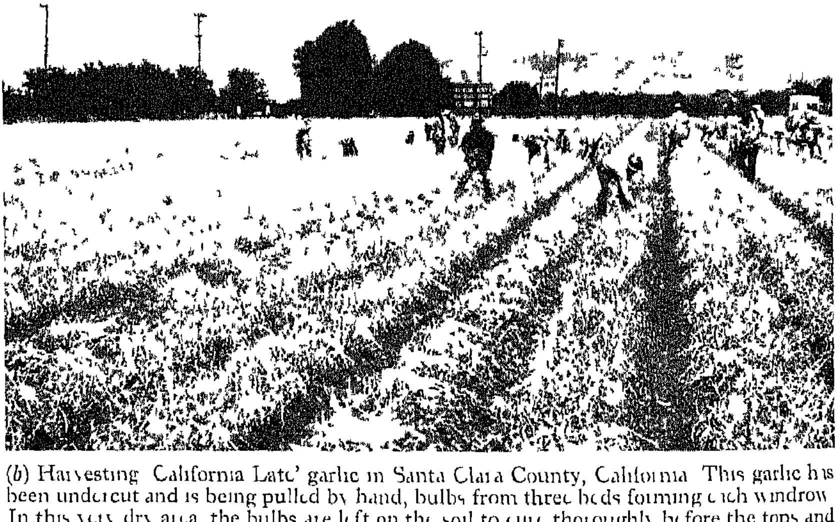


Photo Calif. Agric. Exp. Sta.

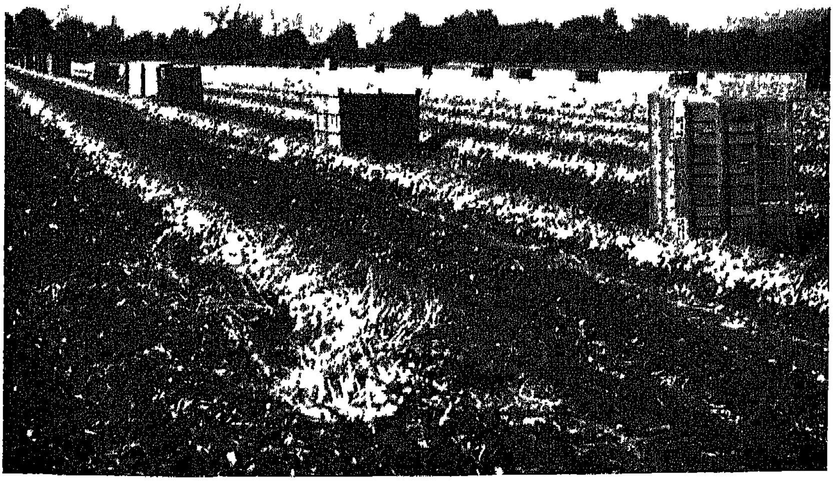
(*a*) California Late’ garlic grown for certified planting stock in Lassen County California The 4-in pipe is for sprinkler irrigation This garlic grown in a quarantined area free from white-rot and nematode, is inspected by a State agency, and will be sold under a tag certifying its freedom from nematodes



(*b*) Harvesting California Late’ garlic in Santa Clara County, California This garlic has been undercut and is being pulled by hand, bulbs from three beds forming each windrow In this very dry area, the bulbs are left on the soil to cure thoroughly before the tops and roots are removed by hand Leaving the bulbs exposed to the sun, as shown here, may result in severe sunburn in hot climates

PLATE 51

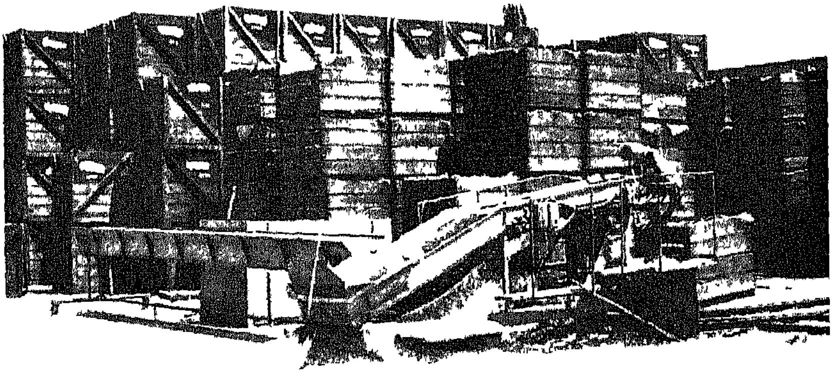
(*a*) The 'California Early' garlic in the background has been topped and sacked, and is ready to be hauled from the field. The 'California Late' in the foreground is curing in windrows. The garlic in the background was infected with nematode, and the debris left in the field will spread this infestation. The bulbs shown in Pl. 54 were from this field.
Santa Clara County, California



(*b*) Large bins, 4 × 5 ft × 41 in. high, used for bulk-handling garlic bulbs. After the tops and roots have been clipped, the garlic bulbs are placed in these bins and thereafter handled entirely by fork-lifts and trucks. Grading is done at a central plant. The bulbs may also be handled in bulk in trucks, or in smaller containers. Santa Clara County, California

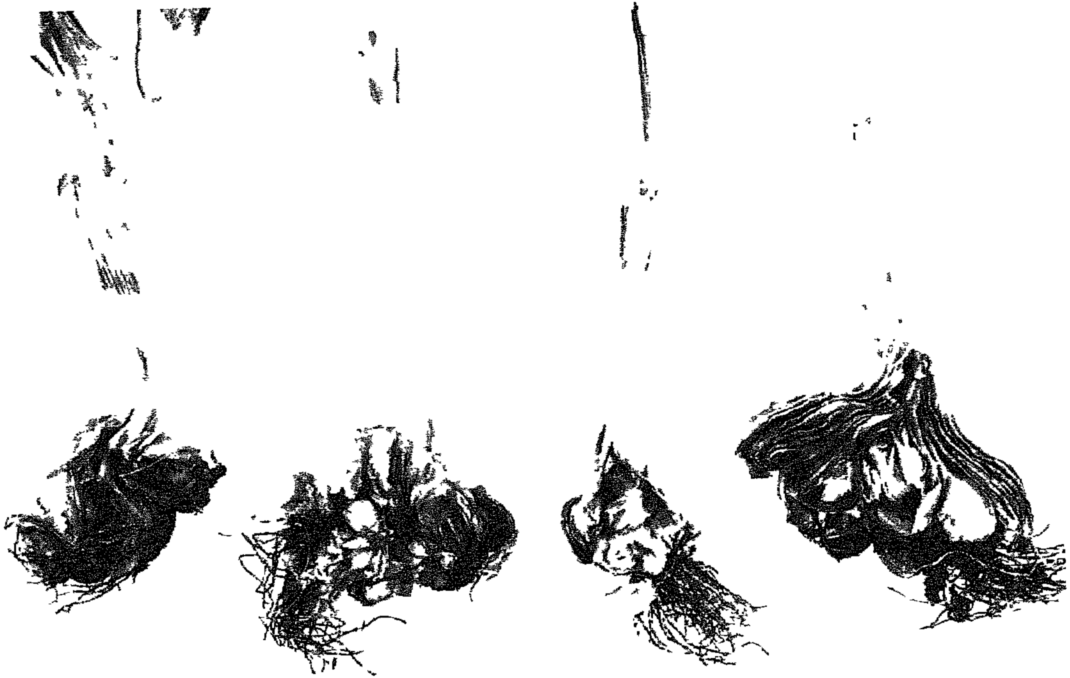
PLATE 52

(*a*) Garlic bulbs for the fresh market must be smooth, free from soil stains, and well cured. As this garlic must keep well in storage, mechanical damage during harvesting, grading, and packaging, must be kept to a minimum. The cardboard and wooden boxes contain 30 lb of garlic, the mesh sacks 25 and 50 lb.



(*b*) Bulk bins of garlic and a garlic grader in the yard of a dehydration plant Santa Clara County, California

PLATE 53



Mature plants of 'California Early' garlic severely infected with the stem and bulb nematode. In growing plants, the basal portion of the false stem when infected becomes swollen, spongy, and sometimes splits. These plants which were nearly normal in size, were from the field shown in Pl. 52(*a*) and, if discarded in the field, will spread and increase the infestation.

PLATE 54

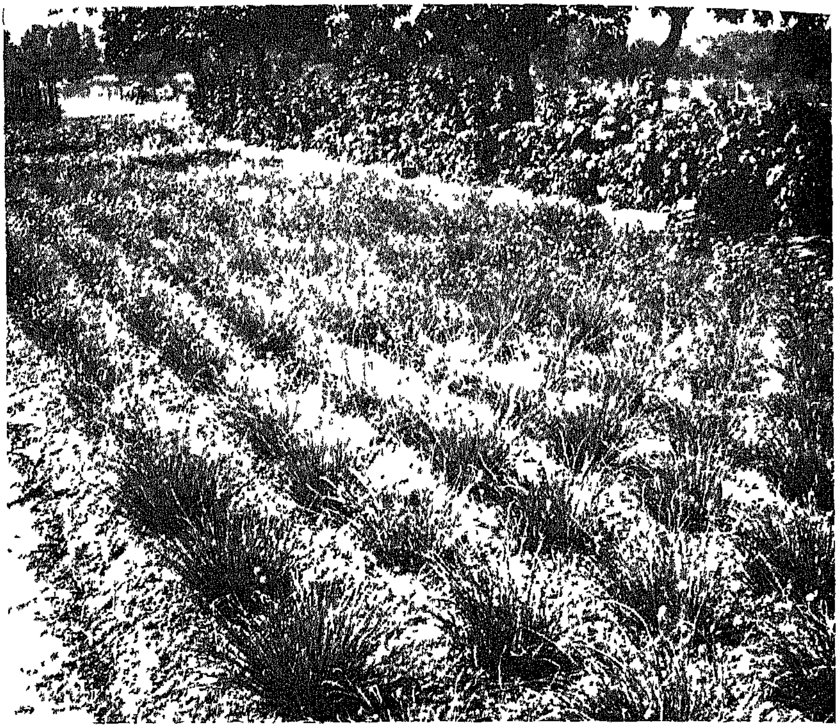
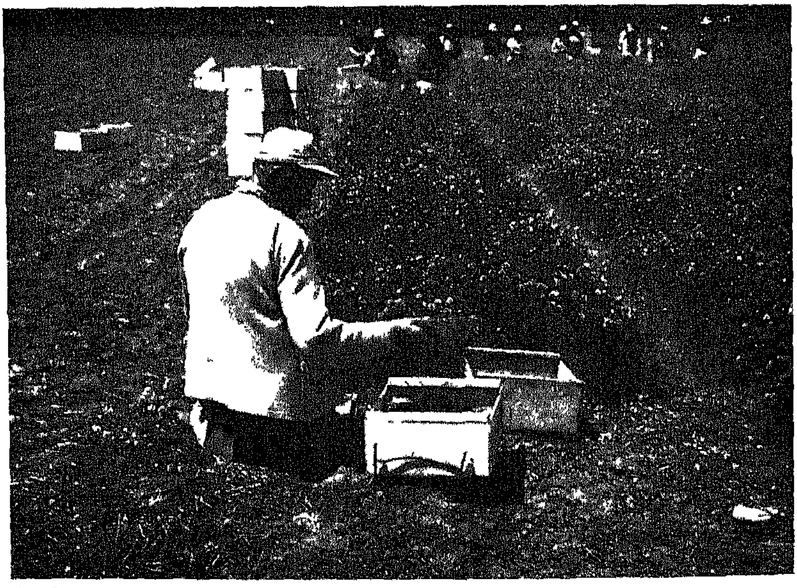


Photo E W Davis

(*a*) A planting of chives for foundation seed Note the wide spacing used here as compared with that of plantings grown for tops (Pl 56(*b*)) Angers, France



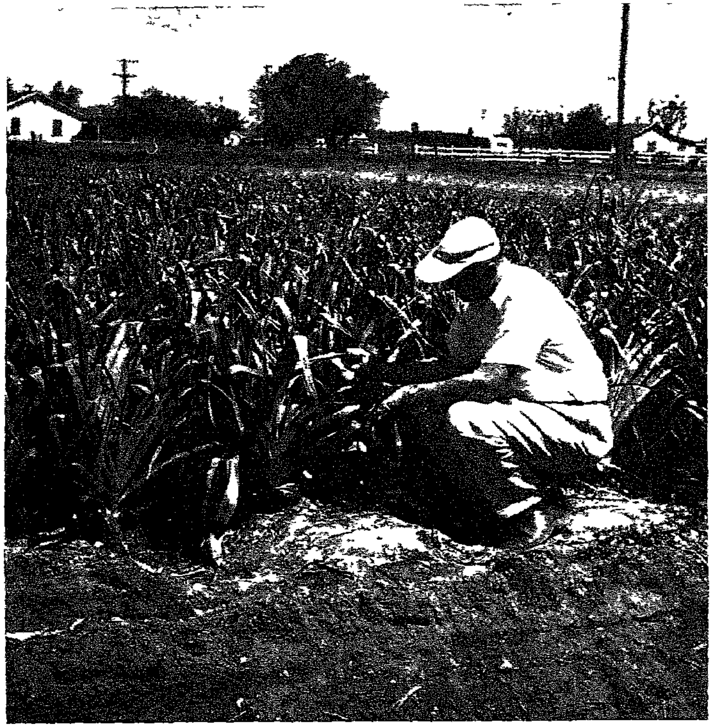
(*b*) Harvesting chives The harvester kneels on a burlap pad and pulls with him a wooden crate set in a wire frame In this April cutting, many flower-stems are mixed with the leaves These stems are discarded before the leaves are placed in the crate

PLATE 55

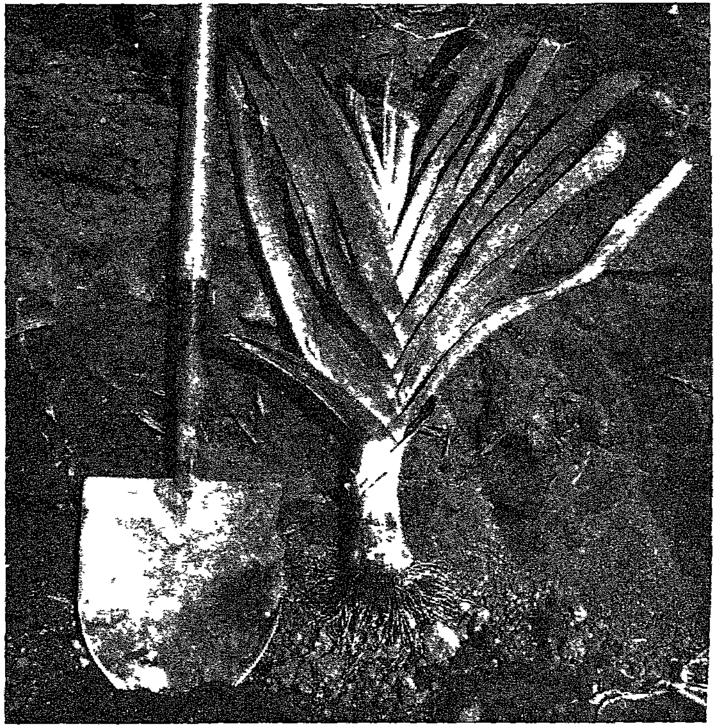
(*a*) A chive field immediately after harvest, showing the closely-cut tops The spaces between the groups of rows are 30 in wide

(*b*) A chive field 4 weeks after cutting The waste material left by the cutters is conspicuous in the broad alleys between groups of rows These alleys are 30 in wide

PLATE 56



(*a*) Leek cv American Flag A field in San Joaquin County, California, photographed in early April Seed for this field was planted in March of the preceding year and transplanted in mid-June The harvesting of small plants could have started as early as November, 8 months after seeding The plants now in the field must be removed by the end of May or they will be useless because of bolting



(*b*) Leek cv American Flag A plant about 13 months from seeding and 0 months from transplanting From the field shown in Pl 57(*a*) are processed as fast as they are received, the storage period is very short; otherwise, they may be held for some time. Acreages are usually contracted for in several production districts, so that the onions will mature at different times; this assures a continuous supply of fresh onions throughout the processing season. When conditions are not satisfactory for curing onions in the field, they may receive additional curing at the plant before being stored.

By using stored onions, the dehydrating season can be further extended into the late autumn and winter, the length of extension depending on how long the onions can be kept in a healthy, dormant condition at temperatures that are suitable for a high-quality dehydrated product. At certain temperatures, the storage life of the bulb is shortened, or changes take place that lower the quality of the dehydrated product. Yamaguchi *et al.* (1957) stored 'Southport White Globe' bulbs at several temperatures ranging from 0° to 40° C. After 4 months, the lots which had been stored at 10°, 15°, and 20° C., gave the lowest yield of both bulbs and flakes. Immediately after drying, there was little difference in the dry flakes from the different storage lots; but when the flakes were held for 15 months at 25° C., the flakes from the bulbs that had been stored at the higher temperatures retained a more desirable, lighter colour than did the others. Bulbs that had been stored at 40° C. were not processed.

Processing begins by grading the onions for size. They are then either flame-peeled or washed to remove the outer dry scales and dirt. Flaming, usually done with natural gas at high temperatures (about 2,000° F.), burns off the roots and the outer dry scales and leaves. The loose, charred particles are drawn off with high-velocity air, and then the onions are washed and brushed under high-pressure water sprays, to cool them and remove the charred skins and dirt. After flaming or preliminary washing, the bulbs are inspected for defects, and the tops and roots are trimmed off by hand or by one of several types of mechanical de-rooters. The onions are then given another washing, inspected, and taken to a rotary slicer where they are cut into slices about $\frac{1}{8}$ in. thick. Onions are not blanched after slicing, as this reduces the pungency of the dried product.

Two types of dehydrators are in use. In one, the onion slices are spread on wooden trays which are then stacked about twenty-five high on cars, and run through heated tunnels for drying. To obtain uniform drying, the slices are spread evenly—usually about $1\frac{1}{4}$ to $1\frac{1}{3}$ lb. per square foot of tray surface. In the newer dehydrators, the onion slices are carried through drying compartments on stainless steel belts, so that they never come into contact with wood during the drying process (Havighorst, 1955). Drying requires 3 or more hours, and takes place in three stages: the initial drying at 165° F., the second drying at 145° F., and the final drying at 130–140° F. Uniform drying is obtained by blowing hot air up and down in alternate compartments of the drying tunnel. As the onion slices need additional drying after leaving the conveyer, they are generally put into finishing bins, where warm air is blown upwards through perforations in the bottoms of the bins, until the moisture content is reduced below 4 per cent. This final drying usually takes about 12 hours. After drying, the onion slices are generally screened into commercially desirable sizes, and some of the material is milled to form products that range in size from fine, flour-like materials to ones resembling coarse salt. However, little of the dehydrated product is sold in the powder form; most is sold in sizes which range from those of rice grains to large rings.

As dehydrated onions are very hygroscopic, extreme care must be taken to prevent moisture pick-up during the final stages of processing. This is especially important to prevent onion powder from lumping. In the packaging room, the relative humidity is usually kept down by the use of dehumidifiers. If they are kept cool and dry, dehydrated onions can be stored for several years, though the containers must be practically moisture-proof. The type of container varies with the product, and may range from small glass jars to 55-gallon drums.

To get the best rehydrated product for salads, onion flakes should be soaked in a minimum amount of water for about 2 hours, either at room temperature or in a refrigerator. The absorbed water makes the onion pieces crisp and succulent. Rehydration, however, is not always necessary or even desirable. If onion is to be used in a concentrated product, there is no need to add water which would have to be removed later. Also, reconstitution and cooking can be accomplished simultaneously—e.g. in making fried onions, the dried pieces are browned slightly in a small quantity of fat, then covered with water, and simmered. When the excess water has disappeared, the fried onions are ready to serve; they are uniform in colour and are preferred, by some people, to fried fresh onions.

Chopped and dehydrated green onion tops are used in restaurants and homes as a substitute for chives in 'sour cream and chives', in a dip for potato chips, as a garnish for baked potatoes, in potato salad, and in other salads where the green colour and mild flavour of the tops are desirable. Dehydrated green tops of the highest quality are made from immature rather than from mature onions. Both the white portion and the very light-green tips are removed before dehydration.

OTHER ONION PRODUCTS

PICKLED ONIONS

Most countries grow onions for pickling, but the amount is usually relatively small. Among European countries, the Netherlands is the most important producer of pickling onions, growing between 1,000 and

1,500 acres per year. Most of these are in southwestern Holland, on contract with the processers of other vegetables and fruits. The ideal pickling onion is white and globe-shaped, and has a small neck and root-zone. The Dutch grow the Italian cultivars Pompei, Barletta, and Regina, to get this type of onion. Seed is broadcast, usually from the middle of February to early April, at the rate of 90 to 100 lb. per acre, on land that is completely free from weeds. Bulbs are harvested by machine from about the middle of July to the middle of August. After the soil is screened out, the roots and leaves are removed by the so-called 'houseworkers'. To lower harvesting costs, machines are being designed to do this latter handwork. Yields are 6 to 10 tonnes per acre. Pickled onions from the Netherlands are shipped to many countries, either as a finished product or in brine.

The production of pickling onions is not of much importance in the United States. About 200 metric tonnes, mostly in brine, are imported each year from the Netherlands—more than from all other countries combined. Considerable quantities of pickled onions are imported from Japan, but these are *Allium chinense* (Chapter XIX p. 242).

Growing and pickling small onions is an industry of some importance in Italy. Onions are pickled in vinegar, either alone or mixed with other vegetables, for use as *hors d'œuvres*. A considerable quantity of small, unprocessed onions is shipped from Italy to other countries. The two white cultivars Barletta and Regina are the most important. They are grown chiefly in southern Italy, where they are seeded in February and March and harvested 2 to 3 months later. Regina is used chiefly for export. The cultivar Borettana is grown mainly in northern Italy, in the province of Parma and other areas of Emilia. The scales are straw-yellow and the flesh is white. Thick seeding, at the rate of 30 to 40 kg. per hectare, is usual for pickling onions. Yields average 7 to 8 tonnes per hectare, but may be as high as 10 to 11.

FRENCH-FRIED ONIONS

French-fries, i.e. onion rings fried in deep fat, sometimes after being dipped in batter, are being packed by the frozen-food industry; some are also being canned. Medium-sized onions, with fleshy rings and single centres, are required, and mild types are preferred.

Small whole onions are also being processed by the frozen-food industry. They are used chiefly by the hotel and restaurant trade for making 'creamed' onions.

XVIII

GARLIC

NEXT to the common onion, the most widely used of the cultivated Alliums is probably garlic, *Allium sativum* L. From its original home in central Asia (cf. p. 36), it spread in prehistoric times to the Mediterranean region, where its virtues are still cherished perhaps more than in any other region of the world. Täckholm & Drar (1954) describe clay models of garlic bulbs that were found in predynastic cemeteries in Egypt: 'In making these a core of clay was first formed, probably globular in shape, and on this were pressed about nine long, sausage-like rolls of clay, the tips being firmly pressed until they adhered to the core. The whole was then white-washed, and presents a very natural appearance.' These early models, dating from before 3,000 B.C., are followed by tomb finds of actual bulbs dating from some 1,500 years later; 6 bulbs were found in the tomb of Tut-Ankh-Amen. Garlic reached China at an early date (Bretschneider, 1892; Laufer, 1919), and was probably carried to the western hemisphere by the Spanish, Portuguese, and French. It is grown and used mainly in countries of Mediterranean climate, and in areas that have been populated by south Europeans. Even today, garlic is little used in the British Isles and over much of northern Europe.

Garlic is a condiment and is only rarely—and perhaps unwisely—used with a heavy hand. Because of convenience and uniformity, dehydrated garlic is replacing the fresh bulbs for industrial and home use in the United States and many other countries. Its importance will certainly continue to increase. In Bulgaria, the Philippines, and much of eastern Asia, the green tops are used as well as the bulbs. This is a convenience, especially where garlic is grown at home, as the tops become available long before the bulbs mature. In some tropical areas, tops may be grown from imported bulbs, even though warmth and short days do not allow the bulbs to form.

WORLD PRODUCTION

Because garlic is a minor crop and is usually grouped with other vegetables in statistical data, no clear picture of world production can be given. However, notes on its production in several countries suggest its relative importance.

Mexico is a large producer of garlic, with the State of Guanajuato in central Mexico producing over two-thirds of the Mexican crop. About half of the crop is exported (7,000 tons in 1958), mostly to the United States, though some goes to Caribbean countries. The increasing importance of the crop may be indicated by the establishment in 1959 of two dehydrating plants (Medina B. & Cásseres, 1960).

In Brazil the main garlic-producing states, in order of importance, are Minas Gerais, Rio Grande do Sol, São Paulo, and Paraná. The area cultivated ranged from about 5,000 ha. in 1944 to over 10,000 ha. in 1956, and yields during this period averaged 2·2 tonnes/ha. In Minas Gerais during this period the value of the garlic produced outranked that of tomatoes and onions combined, and was about one-third that of potatoes (Couto, 1958).

The region of Veneto in northern Italy leads production in that country, followed in descending order by Emilia, Campania, Lazio, and Piedmont. The average annual production for 1956–60 in Italy was about 57,000 tonnes. During the same period, small amounts were imported, while exports, mainly to the United States and Central America, varied from 8,200 tonnes to almost 15,000 tonnes per annum.

In the Philippine Republic some 1,500 ha. are planted to garlic, the Balangas area south of Manila being the most important. As land for producing garlic is limited and imports are restricted, the value of the crop is unusually high.

In eastern Europe, Romania, Bulgaria, and Poland, appear to be the major garlic producers. Romania grew nearly 7,000 ha. of garlic in 1957, Bulgaria 1,450 ha. in 1956.

In Spain, which probably leads the world in garlic production, the area in garlic increased from somewhat less than 13,000 ha. in 1957 to over 15,000 in 1960, when total production exceeded 100,000 tonnes. While only slightly over half of the area of garlic in Spain was under irrigation in 1960, the irrigated areas produced over 70 per cent of the crop. Cuenca province in east-central Spain has some 3,000 ha., mostly grown without irrigation. In southern Spain the provinces of Granada and Cordoba have about 1,700 ha. between them, of which about 70 per cent is irrigated. Other important areas for garlic are the provinces of Valencia, Albaceta, and Gerona, on the Mediterranean coast (2,000 ha., mostly irrigated), and Cáceres and Badajoz on the western border (1,200 ha., all irrigated).

In the United States, most of the garlic which is grown commercially is produced in California. For many years, some 90 per cent of California's crop was produced in the Gilroy district of Santa Clara County, the San Juan Valley of San Benito County, and near Salinas in Monterey County—all areas of moderate summer and winter temperatures. Recently, some of this production has shifted to Kern County and the Imperial Valley.

During the 10-year period from 1947 to 1956, California averaged somewhat more than 2,000 acres under garlic. Each year since 1957 the acreage has increased, reaching a high of 5,400 acres in 1960. Average yields have also increased, from 7,500 lb. per acre in 1957 to 8,500 lb. per acre in 1960. It is estimated that 10 per cent of this crop moves as fresh garlic to California markets, 70 per cent is dehydrated, and the rest is shipped out of the State—mainly to New York and Chicago.

United States imports—amounting in some years to almost half of the garlic consumed—are irregular as to amount and source, but in recent years Mexico, Italy, Chile, Spain, Argentina, and Peru, have supplied most of the imports. Less important have been consignments of dehydrated garlic received from Italy, Japan, Egypt, Spain, and a few other countries.

Egypt probably ranks second only to Spain in garlic production. Between 1957 and 1961, the area in garlic was about 13,200 acres and the average annual production was about 57,500 short tons (1 ton = 0·907 tonne). For the years 1957–60, Lower (northern) Egypt had about 7,900 acres in garlic, Middle Egypt about 3,700 acres, and Upper Egypt 1,456 acres. For this same period the yields averaged about 3·7, 5·6, and 4·4, short tons per acre in these respective regions. Major producing areas are the Minia province in Upper Egypt and the Dakahlia province in Lower Egypt. Next in order are the Kalioubia, Gharbia, and Beheira provinces, in Lower Egypt. While the amount of dehydrated garlic which is exported is small and variable (in 1959, 70 short tons; in 1960, 35 short tons; going mainly to the United Kingdom, Canada, and Germany), the export of fresh bulbs is of considerable importance, and averaged well over 6,000 short tons per year for the three years 1958–60. The main countries of destination during these years were Aden, Ceylon, Malaya, Saudi Arabia, Austria, the Netherlands, Italy, North Vietnam, and British Eastern Equatorial Africa.

In France, garlic is produced mainly in the central, southern, and northwestern parts. The total production increased steadily from 27,500 tonnes in 1956 (on 4,570 ha.) to 46,000 tonnes in 1959 (on 6,900 ha.). Estimates for 1960 production were 35,000 tonnes (on 6,200 ha.). In 1960 about 5,000 tonnes were exported, mainly to West Germany and Switzerland, with lesser amounts to the United Kingdom, Belgium-Luxemburg, and Algeria. Imports for the same year were less than 2,000 tonnes, and came mainly from Italy, with small amounts from West Germany, Algeria, and Tunisia.

In 1959, Japan produced about 9,000 tonnes of garlic on 3,000 acres; estimates for 1960 were about 10,000 tonnes on 3,290 acres. The major producing area is the Chiba Prefecture in central Honshu; the Ibaragi and Niigata Prefectures are also important. In 1959–60, 1,708 tonnes were exported, most of which went to Hong Kong, Singapore, and Malaya, but some small amounts to South Vietnam and other south-east

Asiatic countries. Figures on dehydrated garlic production are not available, but this item is known to be quite small.

Growth and Development

Garlic is usually planted in the late autumn, in winter, or very early in the spring, and begins growth immediately. It grows vigorously as the weather warms in the spring, and matures in spring, midsummer, or early autumn, depending on the locality and cultivar. While garlic is most commonly grown in areas of mild winters without snow, it is extremely frost-hardy. This has been demonstrated recently in northern California, where the crop has been grown at elevations above 4,000 ft. Here it is planted in late September or October, and by November, when snow usually falls, it is well rooted and may, on occasion, have the tops showing above the soil. The mean January temperatures, frequently with only a light snow-cover, average below 0°C., with minima, of course, far lower. Growth starts again after the snow melts in the spring, and the crop matures in August. These early autumn plantings yield well. Spring plantings, on the other hand, may be so delayed by late rains that the growing period before bulbing is too short for satisfactory yields. Comin (1942) has reported similar success with autumn plantings in Ohio.

As with the onion, bulbs form in garlic in response to the lengthening days of spring, and bulbing and maturity are considerably hastened if the temperatures are high. But unlike the onion, bulbing in garlic is influenced by the temperatures to which the dormant cloves (divisions of the large bulb) or growing plants are exposed before bulbing begins. Exposure of dormant cloves or young plants to temperatures between 0° and 10°C. for 1 or 2 months hastens subsequent bulbing; plants that are never exposed to temperatures below 20°C. may fail to form bulbs, even under long days. In most garlic-growing areas, the storage of planting stock in unheated sheds and the exposure of field plantings to the low temperatures of winter or early spring, supply the cold treatment that is necessary for bulbing.

Too much exposure to low temperatures, however, can be harmful. Plants grown from cloves that have been exposed to low temperatures for long periods may initiate cloves in the axils of leaves near the bulb surface, i.e. farther from the bulb centre than is usual. During the growing-season these cloves develop green tops, which appear as lateral shoots to the false stem; and as the plants mature, the loss of a few outer sheaths exposes the outermost cloves, so that the bulbs appear rough.

These responses of garlic to temperatures and photoperiod explain two difficulties that are commonly encountered by garlic growers—roughness of garlic bulbs and the occasional failure of plants to form bulbs. This is well illustrated by Pl. 50, from a late spring planting made at the cool Tulelake Field Station in northern California. As described by Mann & Minges (1958), bulbs of 'California Late' garlic were stored for 9 months at 0°, 5°, 10°, 15°, and 20°C., and the cloves were planted on April 29th. With the advent of long day-lengths and warm field temperatures, the plants from bulbs that had been stored at 0° and 5°C. formed bulbs quickly. As the plants did not reach a large size before bulbing, the bulbs were undesirably small; and, because of the extended exposure to cool temperatures, the cloves formed near the bulb surface, making the bulbs undesirably rough. For the particular conditions of this test—planting date, latitude, and field temperatures—storage at 10°C. gave the best bulbs. Despite the long days at Tulelake (42° N. latitude), the cloves from bulbs that had been stored at 15° and 20°C. did not form bulbs, because they had not received sufficient exposure to cold. Garlic in tropical or subtropical areas may fail to bulb from lack of cool temperatures, and also because of the short day-lengths of low latitudes.

While the storage temperature of bulbs before planting has a profound effect on the bulbing of the plants that are grown from them, it seems doubtful whether controlled-temperature storage will be of much use in commercial areas where garlic has long been grown. In most of these areas, farmers have for years been growing test plots of kinds that were unfamiliar to them. Through this process they have selected those cultivars that are well adapted to local farming methods and to the common storage temperatures of their areas. Furthermore, controlled-temperature storage is quite costly. Cold storage of planting stocks has been tried occasionally by California farmers. Following such storage, emergence may be much more rapid and uniform than in stock that is taken from common storage. This has cultural advantages—for example, in weed control—and early growth is also vigorous; but garlic that has been grown from bulbs receiving much more exposure to low temperature than is received in common storage, is usually too rough to be commercially valuable (cf. Pl. 50).

Growing conditions other than temperature probably affect the roughness of garlic bulbs. Field experience indicates that roughness may be increased by early planting, heavy fertilization, wide spacing, and other factors which favour vigorous growth of individual plants.

The factors controlling bolting in garlic are not understood. Although exposure to low temperature initiates bolting in the onion, this does not seem to be the case with garlic. In any large collection of cultivars there are those in which all plants bolt, some even forming two or more seedstalks per plant. Others, such as 'California Early', have apparently rarely, if ever, been observed to bolt. The reasons for such differences, of course, lie in genetic differences among clones, and recall the variation in the ease of bolting among onion cultivars. Most likely, in those clones in which bolting is variable, factors favouring rapid bulb formation and early maturity are unfavourable to seed-stalk elongation. Among such clones, aborted and partially-exserted seed-stalks are commonly observed. The fact that garlic plants are not readily induced to bolt by exposing the growing plants to cool winter temperatures accounts for the wide range of autumn planting dates that can be used for this crop. Further information on the physiological responses of garlic to its environment can be found in Mann (1952), Mann & Lewis (1956), and Mann & Minges (1958).

CULTIVARS

The many cultivars of garlic that are now known must have arisen as vegetative mutations during the long period of garlic cultivation. The variation among cultivars is great, and conspicuous differences can be found in plant size, yield, content of solids, time of maturity, ease of bolting, storability, and the number, size, shape, and colour, of the cloves.

Most garlic-growing countries use several distinct cultivars to meet climatic and consumer demands. Thus, Mexico grows five cultivars which differ markedly in earliness, yield, and bulb colour, as well as in consumer preference on domestic markets (Medina B. & Cásseres, 1960). In California, three cultivars are grown: 'California Early' is high-yielding and early-maturing, but stores less well and has a lower content of solids than 'California Late'; 'Creole' does well in the hot southern interior, but is little grown elsewhere in the State. In the Philippines, two kinds are grown. One of these, from the Batan Islands, is large-bulbed and yields well, but fails to bulb in the shorter days of most of the Philippine Islands lying farther south. There it is replaced by a small-bulbed, poor-yielding, but very early cultivar. France, Italy, Brazil, Japan, and other garlic-raising countries, each grow several distinct cultivars. Almost without exception these cultivars have local names, and no attempt has ever been made to collect and compare the cultivars of different countries. Improvement by crossing is not possible, but careful selection of clonal lines, along with elimination of bulb-borne diseases, should be helpful.

Large-bulbed forms of *Allium ampeloprasum* should not be confused with garlic (*see* Chapter III). It seems likely that the cultivars 'Tahiti' (Beattie & Beattie, 1938), 'German' (Altstatt & Smith, 1942), 'Elephant' (Howard, 1945), 'Canario' or 'Oaxaqueño' (Sánchez, 1949), and some others, are of this species rather than of garlic.

GROWING THE CROP

SELECTING PLANTING STOCK

Garlic produces no true seed but is propagated by planting cloves, which are the small bulblets making up the whole garlic bulb. These cloves, when used for propagation, are commonly termed 'seed' by garlic growers, but the term 'planting stock' is more appropriate. Most large seed companies sell garlic planting stock, but the established garlic grower usually saves stock from his own commercial crop.

The garlic grower should remember that serious diseases, such as white-rot and stem and bulb nematode, are distributed by planting diseased stock, and that land which is infested by such stock may have to be abandoned for growing all *Allium* crops. The careful grower will select stock only from fields which have been under close observation and are free from clove-borne diseases. Stock should never be taken from fields when showing symptoms of white-rot or nematodes, and only large, smooth bulbs of the best quality should be saved. Imported garlic, garlic of poor quality, and garlic from sources that are unknown to the farmer, should be avoided.

Recently the University of California selected a stock of 'California Late' garlic which was free from stem and bulb nematode and from other pests that were new to, or of limited distribution in, the State. This garlic is being grown by farmers in quarantined areas where garlic and onions have not previously been grown (Pl. 51(*a*)). The California State Department of Agriculture has an inspection programme of the growing area, and planting stock certified free from nematodes was first released in 1960. This programme should be helpful, not only in protecting land for growing garlic, but especially in protecting all clean land on which *Allium* crops might be grown. The cultivars California Early and Creole are being added to the programme. In France the *Centre de Recherches Agronomiques* has a similar programme and plans to release 'Perle d'Auvergne', a selection of 'Rose d'Auvergne', as certified disease-free stock.

PREPARING STOCK FOR PLANTING

Bulbs that have been selected for planting stock are usually stored, with the dry tops attached, in unheated warehouses. Garlic for propagation should not be stored under refrigeration or in heated warehouses, as storage temperature has a marked effect on subsequent crop growth (*see* 'Growth and Development', pp. 213–15).

Some firms regularly fumigate all of their planting stock with methyl bromide before placing it in storage (*see* under 'Mites', p. 226). Because this chemical is hazardous to use, and because it must be applied with rigid adherence to requirements of temperature, dosage, and time of treatment, small lots may more conveniently be dusted with sulphur to control mites, although this may be somewhat less effective than fumigation.

The separation of bulbs into cloves for planting should be delayed until planting time, as whole bulbs store better than prepared cloves. To prepare the cloves, the tops of the bulbs are cut or torn off and the bulbs are broken apart, usually by hand. Where large acreages are to be planted, the breaking of the bulbs into cloves is facilitated by holding the cut top of the bulb over a small pipe which is connected to a source of compressed air. By means of a foot valve, a jet of air (50 to 100 lb. pressure per sq. in.) is blown into the bulb, loosening the wrapper leaves so that the cloves may be easily separated. Another practice is to use large rubber-faced rollers to crush the bulbs partially, so releasing the cloves. The thin, tough, paper-like layer surrounding each clove should not be removed, but all cloves should be separated from one another, or double plants will grow. Breaking the bulbs between rollers has the disadvantage of injuring the cloves. Large cloves are especially subject to injury, and where cloves are graded into sizes before planting, poor stands from the largest cloves may indicate injury during clove separation. Injury can be reduced by grading the bulbs for size before breaking, and then adjusting the rollers for each bulb grade.

Whatever method of clove separation is used, the mother bulbs should be thoroughly dry before breaking. Dry outer coats break away easily, reducing both mechanical injury and labour requirements.

CLOVE SIZE AND SPACING

A number of workers have shown that the size of the clove which is planted affects the size of the harvested bulb (Castronovo, 1950; Couto, 1958; Medina B. & Cásseres, 1960; Paquet, 1961). The relation between the weights of cloves that are planted and the weights of the bulbs harvested from these cloves, as found by Couto, is shown in Fig. 10. Couto observed that a number of other characteristics, such as plant height and weight, were also positively correlated with the weight of planted cloves, but that the number of cloves per harvested bulb was not so correlated. Medina B. & Cásseres (1960) state that, for planting stock that is selected solely on the size of the mother bulbs, yields increased as the size of mother bulbs was changed from small to large. This, again, appears to be an effect of clove size, large mother bulbs yielding, on the average, larger cloves. Couto suggests that cloves which are less than about 1 gm. in weight should not be planted.

Couto (1958*a*) describes two experiments on spacing: in one, all the rows were 40 cm. apart and spacing between the plants in the row was varied from 5 to 17·5 cm. (Fig. 11); in the other, all the plants were spaced 10 cm. apart in the row, and the rows varied from 20 to 50 cm. apart. In both these tests, the yield per unit area diminished and the size of the bulbs produced increased as spacing was increased, although the effect was greatest where the plants were close together. For rows 40 cm. apart, Couto recommended a spacing of 7·5 to 12·5 cm. between plants in the row. This spacing would give 20 to 33 plants per square metre. The recommendations of many writers (*see* Couto, 1958*a*) fall within this range. Paquet (1961) showed that yields diminished as densities

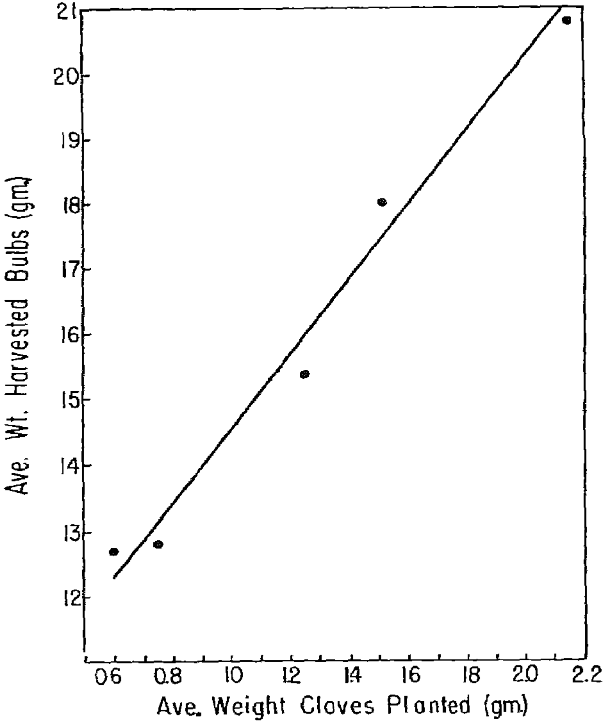


FIG. 10.—Effects of clove size. Regression curve of average weight of bulbs harvested on weight of cloves planted. Bulb size increases markedly as clove size is increased. Redrawn from Couto (1958).

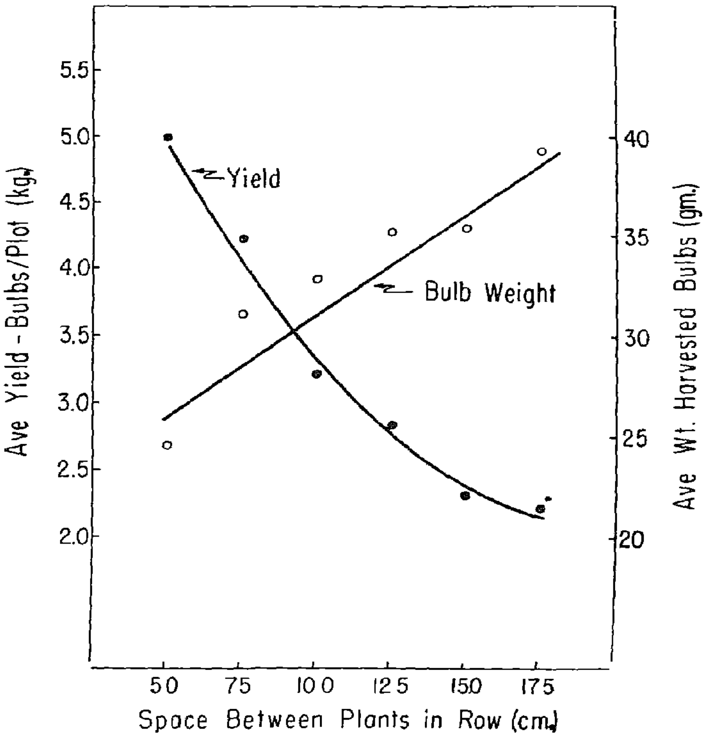


FIG. 11.—Effects of spacing. Regression curves of yield of bulbs per plot and average bulb weight on spacing between garlic plants in rows 40 cm. apart. As the plants are spaced farther apart in the row, bulb size increases but yield per unit area decreases. Redrawn from Couto (1958a)

were decreased from 25 to 15 plants per square metre, and Castronovo (1952), using 12 spacing combinations, found that yield per unit area increased up to the closest spacing tried, namely 30 by 5 cm., or about 67 plants per square metre.

When the cloves are dropped into furrows, either by hand or by machine, they are likely to lie in all positions. Although this may result in plants with crooked necks, yields from such plantings, in contrast with vertical placement of cloves by hand, are apparently not decreased except from those few cloves which stand vertically with the root-end up (Castronovo, 1950; Couto, 1958). For shifting from hand placement to dropping of cloves, Couto suggests an increase of 5 to 10 per cent in the planting density.

In practice, choice of clove size and spacing are so dependent on the cultivar used, the prices of land and planting stock, the bulb size desired, the agricultural equipment available, and the cultural practices followed, that each farmer must determine the best procedure for his particular conditions. It may be an advantage to grade the separated cloves, so that spacing can be adjusted to clove size and the plantings will be more uniform. A suggested trial spacing is 25 to 30 plants per square metre for cloves exceeding 1 gm. in weight. Smaller cloves can be discarded or planted more densely. As a general guide, 800 to 1,000 lb. of mother bulbs (before breaking) may be required to plant one acre (or approximately 900 to 1,100 kg./ha.).

Growers occasionally ask if the small bulbs or top-sets, that are produced in the inflorescence when garlic bolts, can be used for propagation. These top-sets are in no way different from basal cloves, except in their size, which, as indicated on page 37, varies greatly among different cultivars. If they are as large as the basal cloves, they will produce as well. Usually they are much smaller, and will produce marketable bulbs only after 2 years of growth. In some areas, such as California, cultivars which bolt are not commonly grown. Not only do the seeds-stalk and large mass of top-sets reduce the size of the basal bulb by robbing it of food, but the hard seed-stalk makes topping difficult and leaves an undesirable core in the trimmed bulb.

PREPARATION OF LAND AND PLANTING

Preparation of the land for planting garlic cloves is similar to that for onion seeds or sets (*see* pp. 125, 127). The soil should be sufficiently well tilled to allow easy insertion of the cloves, or to permit smooth furrowing, and some provision must usually be made for irrigation. Garlic has been successfully grown on a wide variety of soils, and any soil that is ordinarily suitable for row crops will probably be satisfactory for garlic.

Cloves may be planted by hand, either by placing them individually in the prepared soil or by dropping them into a furrow, which is then covered over. Sometimes a sharp stick or similar tool is used to make a hole in which the clove is placed. Garlic planting machines are usually modified bean planters with small cups on belts which run up through hoppers of cloves. Each cup picks up one or two cloves and drops them down between a shoe which opens the furrow and blades which close it. All of these planting methods work well, and a choice among them depends on variables such as the size of the area planted and the price of labour. In California, where labour costs are high and individual garlic plantings large, all farmed garlic is now machine-planted. These machines are equipped to spray or dust for white-rot as the garlic is planted—a feature which has favoured their use (*see* Pests and Diseases, pp. 227–8). If the soil is dry, irrigation should immediately follow planting, as early sprouting appears to decrease seed-piece decay (*see* Penicillium Decay, p. 228).

FERTILIZING

The object in fertilizing is to apply nutrients to make up the difference between what the crop requires and what the soil can supply. Some soils may produce good yields of garlic without fertilization, particularly if previous crops have been heavily fertilized. Many soils are likely to be deficient in nitrogen, and some soils may be deficient in phosphorus and potash; but most soils adequately supply all of the other nutrients which the crop needs. A well-illustrated study of the deficiency symptoms of garlic to N, P, K, Ca, Mg, and B, has been presented by Couto (1956).

As nitrogen is the nutrient element which is most likely to be deficient, it is best to apply it at the rate of 60 to 80 lb. of actual (i.e. elementary) nitrogen per acre unless previous experience has indicated that there is no need to add nitrogen. This amount can be supplied in 300 or 400 lb. of ammonium sulphate per acre. At least half of the nitrogen should be applied at the time of planting, and the rest added as a side-dressing or in the irrigation water during early spring. Little response is likely to be obtained if the fertilizer is applied after the bulbs begin to enlarge.

Very sandy soils, or exceedingly heavy soils, may also show deficiency of phosphorus—especially during the winter and early spring months. For phosphorus to give the most benefit, it should be applied near the time of planting, and it should be placed fairly close to the plant row. A good method of placement is in a band 4 to 5 in. below the plant row, and 1 or 2 in. to the side. About 350 lb. of single superphosphate (18 per cent P_2O_5), or 150 lb. of treble superphosphate (44 per cent) per acre, is adequate.

If both nitrogen and phosphorus are to be added, ammonium phosphate (16 per cent N, 20 per cent P_2O_5) is a desirable fertilizer. Although band placement is considered the most satisfactory method of application when the proper equipment is available, mixing the fertilizer in the bed at the time of forming the ridge will give good results.

CULTIVATION AND WEED CONTROL

Some cultivation is required for weed control, and for maintaining the beds if furrow irrigation is used. Because garlic is shallow-rooted, deep cultivation should be avoided, as root pruning slows growth and reduces yields. Cultivation with knives and cutters will adequately take care of weeds in the furrow and on the sides of the bed. Removing weeds in the plant row must be done by hand hoeing or with chemical weed-killers.

Small weeds that sprout prior to the emergence of the garlic, can be killed with weed oils such as the refined carrot oils or stove oil. From 25 to 75 gal. of oil are needed on an over-all acre basis, but this amount can be reduced if only the tops of the beds are treated. Oils have also been used to kill weeds after emergence, while the garlic plants are less than 2 in. high. Such a treatment kills the young garlic leaves as well as the weeds; this retards the plants somewhat, but the garlic sends up new leaves and usually recovers fully.

The use of CIPC (isopropyl N-(3-chlorophenyl) carbamate), applied as a pre-emergence soil treatment, can greatly reduce growers' weeding costs. Four to 6 lb. of the active material per acre, in 20 to 70 gal. of water, should preferably be applied immediately after planting and before weed emergence. This controls many annual weeds, but rain is required to carry the chemical into the weed-seed zone. If there is no rain within a few days after application, it is necessary to irrigate with a sprinkler. Furrow irrigation is generally not effective in carrying the chemical into the weed-seed zone. The above rates may be too high in very sandy soils, as under some climatic conditions injury to garlic in sandy soils has been observed.

Selective weed-killers such as the dinitros (ammonium salt of 4,6-dinitro-*o*-sec-butylphenol) and potassium cyanate (KOCN) may be used to remove broad-leafed weeds from young garlic plants (up to 6 in. high for the dinitros and up to 12 in. high for potassium cyanate). These materials are effective only when the weeds are small and tender. The dinitro selectives should not be used when the plants are wet, and the potassium cyanate is of little value when the weather is cool. For detailed information on these and other weed killers, local Agricultural Experiment Stations or similar sources should be contacted.

As garlic has considerable ability to grow through heavy mulches, a 3-in.-thick mulch of organic materials such as rice straw or sugar-cane leaves, placed over the rows after planting, may be quite effective in controlling weeds. However, Couto (1958) reports that certain weeds, such as *Oxalis violacea* L. and *Cyperus rotundus* L., are not controlled by mulches.

IRRIGATION

The bulk of the world's garlic crop is grown under irrigation, and the best yields are obtained if garlic is never allowed to run short of moisture from the time of planting to the first signs of maturity. If periods of drought occur during the growing-season, a rigid irrigation programme will be needed. As garlic is rather shallow rooted, with most of the roots limited to the upper 2 ft of soil, the soil should be wetted to this depth at each irrigation. The next irrigation should be applied when the uppermost foot of soil begins to show depletion of moisture. Garlic is commonly irrigated by the furrow method, but sprinklers are used where the furrow method is impractical (Pl. 51(*a*)). In the Philippines, where all the garlic is planted in paddies following rice, sub-irrigation is used, the water being run around or across the plantings in ditches, from which it moves laterally beneath the soil surface.

As the crop approaches maturity—i.e. when the tops first begin to break over or become dry—irrigation should cease, so that the field will dry out for harvesting. Continued irrigation as the crop matures causes rotting of the roots and bulb scales. This decreases the market value of the bulbs, by discolouring them and exposing the outer cloves.

HARVESTING, GRADING, AND STORING

When the tops become partly dry and bend to the ground, the garlic is usually ready for harvest. Where the garlic is planted on beds, a tractor-pulled cutter-bar or a rotating square bar may be run beneath the bulbs to loosen them. The rotating square bar is especially useful in heavy soils which form large clods. In dry areas the bulbs are usually pulled by hand and the products of several rows are gathered together into windrows (Pl. 51(*b*)). The tops are placed uppermost in the windrow to protect the bulbs from sun, and the garlic is left in the field for a week or more to dry thoroughly.

In areas where rain or dew may occur at harvest time, curing may be more difficult. Thus, for central France, Paquet (1961) recommends pulling the bulbs as quickly as possible after the leaves begin to yellow, removing the tops and roots, and placing the bulbs in slatted boxes in open, well-ventilated sheds. By this procedure, severe neck-rot in storage can be avoided. Smith *et al.* (1944), after a thorough study of bulb curing in Texas, recommend curing for 10 to 14 days on wire racks, either in an open shed or in a barn loft. However curing is accomplished, the bulbs must be thoroughly dried before being shipped or stored. Attempts are being made on some Californian farms to mechanize harvesting as completely as possible. The garlic tops are removed by mechanical shredders before digging, and the topped bulbs are dug, separated from dirt and weeds, and run into bags —all in one operation.

Harvested garlic may be handled in any of several ways after curing. The bulbs may or may not be graded for size, but diseased and damaged bulbs should be sorted out. The sound bulbs may be braided or bunched together by their tops, or placed in crates with the tops and roots attached; or the tops and roots may be cut off with sheep shears, and the bulbs placed in slatted crates or open-mesh bags (Pl. 52(*a*)). Recently, bulk storage in bins, as is used for some onions, has been tried (Pl. 52(*b*)). Crates, bags, or other containers, must be stacked so as to provide adequate ventilation. Bunched or braided garlic is usually hung in shaded locations where ventilation is adequate. In California, where most garlic is topped after curing, grading is facilitated by passing the bulbs over a sloping, slotted table with 1¼ in. openings. Garlic tops and roots, and litter from cleaning and grading, should be removed from the field and burned, to help prevent the build-up and spread of diseases (Pls. 52(*a*), 54).

Garlic may be marketed immediately after curing (Pl. 53(*a*)), but usually the cultivars which keep well are stored in warehouses for several months. When properly cured, garlic stores well under a wide range of temperatures, and controlled-temperature storage is generally unnecessary. As sprouting of cloves occurs most quickly after bulbs have been stored at temperatures near 40°F., prolonged storage in this range should be avoided. Storage at 32°F. appears satisfactory, but is expensive, and high humidities are common in storages at low temperatures. Garlic stored at humidities above 70 per cent at any temperature will not only mould but will have roots emerging from the base of the bulb.

While the above methods of garlic culture prevail in most areas of the world, in a number of countries garlic is grown for the use of its tops as well as bulbs. In China, especially, the tops and even the seed-stalks are eaten. Dr Robert C. Tang informs us that, in northern and central China, both green and blanched tops are used. For the green crop, cloves are planted in July. These are spaced 3 by 3 in. on 4-in.-wide beds, and 3,500 lb. of bulbs are required to plant an acre. The cloves are planted about 1 in. deep, and when the plants are about 3 in. high, they are side-dressed with fertilizer. Harvesting of the entire plant starts about November.

The crop for blanching in northern and central China is planted in mid-August in flat-bottomed furrows 1 in. deep, 3 in. wide, and 6 in. centre to centre. With the cloves spaced about 2 by 2 in. in the furrow, about 5,000 lb. of bulbs per acre are required. The furrows usually run in an east-west direction and may have windbreaks between them. The cloves are planted about 1 in. deep; when the plants are about ½ in. high, they are covered with soil, this process being repeated until the furrow is filled. The whole plants are harvested when they are relatively small. Yields are commonly 20,000 lb. per acre.

DEHYDRATION

In the United States and several other garlic-producing countries, the proportion of the crop which is used for dehydration has increased markedly in recent years. Garlic makes an excellent dehydrated product, and its use in the dry form will probably continue to increase.

As the process of garlic dehydration is quite similar to that described for onions in Chapter XVII, only the differences which are peculiar to garlic will be noted here.

The cultural practices for fresh market garlic and for garlic that is to be dehydrated are essentially alike, although special efforts may be made to produce a smooth, white bulb for the fresh market. Cultivars with a white flesh colour (some have pale-yellow flesh) and a pale colour of the skins surrounding the cloves, are preferred for dehydration, as the final product should be as white as possible.

Garlic is brought to the dehydrator after the bulbs have been thoroughly dried in the field and the tops have been removed. It may or may not be passed over inspection belts at the dehydrating plant (Pl. 53(*b*)); this will depend on the condition of the crop and the thoroughness of field grading. The bulbs are mechanically cracked—i.e. broken apart into separate cloves—by passing under a series of rollers, and most of the dry skins, roots, stems, and other debris, are sucked off by a stream of air. The cloves are then washed, inspected for defects, sliced, and placed on drying trays or belts as with onions. The cloves are usually sliced thinner ($\frac{1}{32}$ in.) than onions, and the trays loaded more heavily. After tunnel drying and final bin drying to below 6·5 per cent moisture, the slices are screened and then aspirated to remove the dry scales which still surround each clove at the time of slicing. The dry slices are then inspected, ground, sieved, and packaged. Unlike onions, where slices and large pieces are desired, most dehydrated garlic is sold in the powdered or granulated form. It usually requires between 2·2 and 2·6 lb. of sliced fresh garlic to yield 1 lb. of dry garlic, and between 3·2 and 4·5 lb. of garlic bulbs from the field to make 1 lb. of the dried product.

PESTS AND DISEASES

PRECAUTIONS

Because of the extremely *poisonous* nature of many insecticides and fungicides to humans, livestock, and beneficial insects, and because legislation controlling their use on food crops is being widely enacted, local agricultural and law-enforcement agencies should be consulted before they are used. For further details *see* Chapter XVI.

STEM AND BULB NEMATODE

This is a small worm-like organism, *Ditylenchus dipsaci* (Kühn) Filipjev, ordinarily invisible to the naked eye, which may infect the bulb and stem of the garlic plant. The basal portion of partly mature plants becomes swollen, spongy, and frequently broken by longitudinal splits (Pl. 54). This is followed by decay and rotting of the tissues involved. There is also a stunting of growth, and usually a twisting and rolling of the leaves and stems. In severely infested plants the stem plate may be rotted so badly that it pulls away when the plant is lifted, leaving the roots in the ground. Once introduced by planting infected cloves, nematodes may persist in the soil for many years. Care must be taken to select planting stocks which are as free as possible from nematodes, as no control method is available for disinfecting such stocks. In California, certain cultivars appear somewhat less susceptible to nematodes than others, but all will go down with severe infestations. Garlic is of special importance in nematode spread because it is vegetatively propagated and widely grown. For information on nematode-free planting stock of garlic, *see* Selecting Planting Stock, pp. 215–16.

Where this pest becomes established, crops other than garlic and onions should be grown. Other hosts to the bulb and stem nematode are Shasta pea (*Pisum sativum* L.), parsley (*Petroselinum crispum* Nym.), celery (*Apium graveolens* L.), salsify (*Tragopogon porrifolius* L.), and several common weeds. The common potato (*Solanum tuberosum* L.), contrary to statements in the literature, is not a host. All of the commonly cultivated onions are hosts and, therefore, should never be grown following garlic. There have been many instances of severe injury to onions where this practice was followed. Cultural operations, particularly allowing cull garlic and harvest litter to become spread over fields (Pl. 52(*a*)), may distribute and increase nematode infestations. Field infestations of this nematode have been controlled experimentally with pre-planting soil fumigation. In California, the best control has been obtained with applications of dichloropropene-dichloropropane mixture (proprietary names such as D-D Mixture) at 50 gal. per acre. The dosage is split into two equal applications from 1 week to 10 days apart, the field being ploughed between applications. Application should be made at least 35 days before planting. Dichloropropene is also recommended at 40 gal. per acre in a similar split application. Planting should follow dichloropropene treatment no sooner than 14 to 21 days. In France, Paquet (1961) recommends 300 l. of dichloropropene-dichloropropane mixture per ha., injected every 30 cm. at a depth of 20 cm.

The use of bromine-containing nematocides should be avoided in pre- or post-planting treatments of fields that are used for growing onions or garlic. These nematocides include all formulations of such materials as ethylene dibromide and dibromochloropropane. Onions and garlic are very sensitive to bromine residues in the soil, and, in general, satisfactory crops of onions and garlic cannot be grown—sometimes for as long as a whole year—after the soil has been treated with bromine-containing materials.

ONION THRIPS

This insect, *Thrips tabaci* Lindeman, is perhaps the most important insect pest attacking garlic. Thrips are most common during warm weather and feed on leaf surfaces, causing them to whiten or 'silver'. If white spots which run together to form larger silvery areas are seen, thrips should be sought. Chemical control must be applied when the young insects are found in the leaf angles, and may have to be repeated at frequent intervals if the infestation continues. Control usually depends on thorough coverage of the bases of the leaves, where the young insects hide. Many insecticides, such as DDT, Parathion, Toxaphene, and Dieldrin, are now used to control thrips. For details on life-cycles, control, etc., *see* Chapter XVI, pp. 196–7.

MITES

The eriophyid mite, *Aceria tulipae* Keifer, is a common pest of garlic, though no estimates are available of the amount of damage it causes. This mite is so minute as to be difficult to see, even with a hand lens, and infestations are frequently overlooked.

Young plantings of garlic that have been injured by mites usually have distorted and twisted leaves with conspicuous yellow or light-green streaking. The leaves may not emerge readily from the cloves, and the leaf-blades separate poorly after emergence. This damage appears to result from injury to the young leaves while the bulbs are in storage, and although the mites may be abundant in the folds of the leaves, plants in the field usually recover and appear normal later in the season.

Bulbs that are stored for long periods may be severely attacked by mites. The cloves wither and the bulbs lose their firmness.

In addition to the eriophyid mite, at least two species of bulb mites (*Rhizoglyphus callae* Oudeman and *Glycophagus domesticus* Degeer) may attack bulbs in storage. These bulb mites develop in the cloves in great numbers, and are readily seen with the naked eye or a hand lens. With a heavy infestation, most of the cloves in the bulbs may be destroyed.

Control measures against mites should perhaps be taken only when these mites are doing evident damage, or when garlic from fields that are known to be infested is to be stored. Fumigation of the dry bulbs with methyl bromide after harvest and before storage will control all of the above mites. A dosage of 2 lb. of methyl bromide per 1,000 cu. ft of fumigated space for 2½ hours at 80°F. is recommended. Methyl bromide is *poisonous* and must be used according to the manufacturer's directions.

Treating the bulbs before storage with enough dusting sulphur to form a thin film over the bulb is successful in killing mites and in preventing their spread from bulb to bulb. But once mites are established inside the bulbs, sulphur will not kill all those present.

In addition to the pests mentioned above, certain mites, particularly the brown wheat-mite or Petrobia mite, *Petrobia latens* (Müller), may damage garlic in desert areas. Red spider-mites of the genus *Tetranychus* may occasionally attack the foliage of plants in the field.

MINOR PESTS

Garlic is closely related to the common onion, and most onion pests will attack garlic. The following onion pests may occasionally be found on garlic, or may be serious pests of garlic in certain areas—particularly if onions have been grown in rotation with garlic.

The Japanese onion aphid, *Micromyzus formosanus* Takahashi, may be an occasional pest on sprouting bulbs in storage, or on young plants in the field in coastal areas.

Wireworms of the genus *Limonius* attack bulbs in the field. Soil treatments or fumigation before planting must be used to control wireworms. Treatments should be applied to fields where wireworms are known to occur, or on new land where they are suspected.

The onion maggot, *Hylemya antiqua* Meigen, may attack garlic plants in the field after the bulbs are formed. It is primarily a pest of cool areas, and is usually present only where onions have been grown previously. The maggots, which are white and legless, may be found in the bulb and stem (*see* Chapter XVI).

Apart from the above onion pests, the cacao moth, *Ephestia elutella* (Hübner), is reported to be a serious pest of garlic in the Philippines, where it attacks and destroys the bulbs in storage.

WHITE-ROT

This disease, caused by the fungus *Sclerotium cepivorum* Berk., attacks garlic in the field. The bulbs are invaded and rotted by the fungus, although the most conspicuous symptom is a yellowing and wilting of the leaves, usually on plants which are from one-half to fully grown. Lightly infected bulbs may carry the disease through storage, and as it may persist in the soil for several years, care should be taken to select seed from fields that are free from this disease. Spreading cull bulbs and garlic litter over the fields at harvest time will increase and spread infection. For further notes on characteristics of the fungus, *see* Chapter XV.

Recent experiments in California indicate that spraying or dusting pentachloronitrobenzene, known by such proprietary names as Terraclor and PCNB, on the cloves and in the row at the time of planting, gives good control of white-rot in severely infested soils. It is suggested that 27½ lb. per acre of a wettable powder containing 75 per cent of pentachloronitrobenzene, or 10 gal. of the 20 per cent emulsifiable concentrate in 100 gal. of water, or 50 lb. of a dust containing 40 per cent of the active material, be used. It is applied from a mechanical planter and is sprayed or dusted into the furrow as this is opened, and on to the cloves and surrounding soil as the cloves are dropped. For hand planting, some protection can be obtained by treating the cloves with 13½ lb. of 75 per cent pentachloronitrobenzene per 1,000 lb. of cloves. Paquet (1961) suggests placing 20 kg. of cloves in a container, moistening with water, and mixing thoroughly with 100 gm. of the commercial product. On heavily infested land only partial control of the disease is obtained.

PINK-ROOT

This common disease of onions, caused by the fungus *Pyrenochaeta terrestris* (Hans.) Gorenz, J.C.Walker, & Larson, also attacks garlic. It produces a pink coloration of the roots and causes their eventual death. Although the organism infects many plants and is widely distributed, control measures are not generally used. If soil becomes so severely infested as to reduce yields, long rotations should be practised or other crops than garlic should be grown. For further details on characteristics of the fungus, *see* Chapter XV.

PENICILLIUM DECAY

The fungus *Penicillium corymbiferum* Westling may attack garlic in storage or in the field (Smalley, 1957). This fungus generally invades the thick, fleshy part of the clove, which softens, shrivels, and finally comes to show blue-green areas of dust-like spores. Plants in the field are attacked when quite young, and may die even before the tops have emerged from the soil. Bulbs that are infected at the time of harvest may decay in storage, the decay progressing over a long period.

Infection appears to be carried on the planting stock rather than in the soil. Many sound bulbs carry the fungus on their outer scales, and while all bulbs that show any infected cloves should be discarded, infection generally cannot be avoided by stock selection. Injured cloves are especially subject to attack, and practices such as machine breaking may increase the disease by mechanically injuring the cloves and by spreading spores. As high moisture levels in the soil appear to suppress decay, a thorough irrigation immediately following planting seems likely to be helpful.

GARLIC RUST

Garlic leaves or stems infected by *Puccinia porri* (Sow.) Wint. bear small, reddish, raised pustules and may be killed by severe infections. Garlic rust was observed in California in 1934, and in 1940 there was light to heavy infection in many fields (Gardner, 1940; Yarwood & Gardner, 1941); but it appears not to have been reported since that time. Dr M. Chorin, of the Agricultural Research Station, Beit Dagon, Israel, writes us that this disease is a limiting factor in garlic growing in Israel. Paquet (1961), in France, recommends Bordeaux mixture as soon as any attack is evident. Knott & McCallum (1942) note that Bordeaux mixture or lime-sulphur, with appropriate spreaders, has given control in experimental trials but not under field conditions.

OTHER DISEASES AND DISORDERS

In addition to the above diseases, *Botrytis allii* Munn, and possibly the related species which cause neck-rot of onions, may occasionally attack and rot garlic bulbs. For precautions against neck-rot, *see* Chapter XV. Another fungus, *Macrophomina phaseoli* (Maub.) Ashby (*Sclerotium bataticola* Taub.), may be found on the outer dry scales of garlic bulbs. It produces a uniform grey coloration of the outer bulb scales, but does not attack the cloves.

Ramsey & Wiant (1941) have described a waxy breakdown of garlic in which some of the outer cloves of the bulb become deep-yellow or amber-coloured throughout, and somewhat sticky or waxy to the touch, but not soft. No organisms appear to be involved, and these authors add that it is not known whether the symptoms are due to high temperature, sunscald, or some physiological disturbance. In California this disorder has been observed on the upper surfaces of bulbs exposed to the sun in the field. Shaded bulbs showed no waxy breakdown, so it appears that sunscald may at least be one cause of this defect. It has been reported to be quite serious in some consignments of garlic imported into the United States.

XIX

OTHER ALLIUMS CULTIVATED FOR FOOD

THE cultivated Alliums which are to be described in this chapter are of less importance in world commerce than either the common onion or garlic. This does not mean, however, that they are unimportant; the Japanese bunching onion is the main vegetable onion in some far-eastern countries, and rakkyo and Chinese chives, though little known in the West, are grown extensively in eastern Asia. For some species, such as the chive, few figures on production and use are available. None the less, the chive is raised in many parts of the world as a vegetable or 'herb' of the home garden, where its small size and great adaptability make it more useful than the common onion. In the aggregate, the use of the less-well-known Alliums is considerable, and even in countries where common onions are the main Allium crop, relatives, such as the chive and leek, with their characteristic flavours and uses, add variety to our onion diet.

Little or no information is available on the pests and diseases of several of the Alliums which are described here. As a general rule, one can assume that the pests and diseases of the common onion and garlic will attack many of these other species also, and that the control measures which are useful on onions and garlic will at least suggest measures to be used with other species and varieties. Thus, for example, the stem and bulb nematode infects most if not all of our food Alliums, and the practices of soil fumigation and sanitation, and, above all, the use of clean seed or planting stock, apply generally as control methods. There are important exceptions, of course; the resistance of the Japanese bunching onion to several diseases of the common onion is well known.

Chemical weed-control methods that are useful on garlic and onions should be applicable to some extent to other species. Non-selective pre-emergence sprays, such as weed oils, may be used in the same way on all species. Selective chemicals are frequently very specific in their action and cannot be used without adequate testing. Residue problems also vary with methods of application, and with the plant parts that are used for food and the amounts that are consumed.

CHIVES (*Allium schoenoprasum*)

Probably more than any of the vegetable Alliums, chives are plants of the home garden. Their tufted habit, attractive green foliage, and purple flowers, make them useful as ornamental edging plants or for growth in clumps among other herbs. Chives are completely hardy to cold, withstand drought, and grow well in a wide variety of soils. The tops may be cut for use from early spring throughout the summer, and the clumps are easily propagated by division. Few herbs are more attractive, adaptable, or useful for the small garden.

Chives do not produce well-defined bulbs, and only their green tops are eaten. These, because of their bright colour and tenderness, may be used as a garnish or, because of their mild flavour, as a condiment in soups, stews, salads, omelettes, sauces, and sandwiches.

Wild chives are common native plants of the northern hemisphere (Chapter III), and have probably been introduced into our gardens many times. Although chives are extremely variable, both in the wild state and in cultivation, only a few cultivars have been named (Chapter III), probably because of their limited commercial use.

We know little of the early history of chives as cultivated plants. Helm (1956) states that they were used in Europe in the sixteenth century, and were introduced into culture in Germany by the Italians. While they are commonly marketed in large cities, frequently by forcing plants in glasshouses during the winter, when few other greens are available, and while there is a small but important industry in California producing fresh-frozen chives, none the less, chives are primarily a home-garden crop. They are uncommon in southern countries such as Spain, and apparently almost unknown in Egypt; but they are widely grown in northern Europe. Professor Emil Chroboczek writes us that production of chives in Poland may amount to 5 per cent of the production of bulb onions, and that they are to be found in every home garden. Vvedensky (1946) notes that chives are sometimes cultivated in the western zone of the European part of the U.S.S.R., and that in Siberia they are salted for winter use.

As might be expected of a herbaceous plant that is native to cold northern areas, chives become dormant during the winter months. Leaves and flowers are produced abundantly during the spring and early summer and, if the tops are cut, leaf production will continue until rest begins in September or October. Chives are commonly marketed by dividing clumps into small pots, which are sold after forcing top-growth. If well cared for, such a pot will supply the housewife with tops for several weeks. However, when chives enter rest in the autumn, this top-growth may be weak, irregular, or even absent. McCollum (1936), working in Illinois, tried to break the rest period of chives by a wide variety of treatments. He found that storage at low temperatures decreased rest, but the treatments were impractically long and costly. However, by heating the plants to 110°F. for 36 to 48 hours before potting, vigorous top- and root-growth could be stimulated. Apart from this study of McCollum, we know little of the physiology of chives, either in flowering or in rest.

Chives may be increased by vegetative multiplication or by seeding (Pl. 55(*a*)). For commercial crops, seeding is preferable, as it allows better control of diseases. Levan (1936–37) has shown that there is great variation in fertility among different chives, depending on chromosome numbers and cytological irregularities. These observations may explain in part the statement, which is common in horticultural texts, that chives rarely seed.

Chives are subject to the stem and bulb nematode, downy mildew, and pink-root. Chittenden (1951) indicates that they may suffer from rust, and Walker (1952) lists other diseases. We have no information on insect pests, but those attacking other *Allium* species might be expected to attack chives. Pest control measures used on onions should be effective on chives, but special precautions should be taken to avoid residues on the foliage.

Some of the practices of commercial chive production are illustrated by a planting in San Mateo County near San Francisco Bay, where about 20 acres are grown for freezing. Here the chives are seeded on the flat (2 lb. of seed per acre) in midsummer or autumn and the plants are irrigated by sprinklers. The planting shown in Pls. 55(*b*) and 56(*a*) was seeded in July, first harvested in November of the same year, and harvested again the following March. These pictures were taken during the third harvest, in late April; successive harvests will continue at 4- to 5-week intervals throughout the summer and autumn. The best cuttings are obtained in the second year after planting, and after the third or fourth year the field is re-seeded. Weed control is by cultivation, and no rotation is practised.

As shown in Pl. 56(*b*), the chives are seeded in single rows which are spaced 14 in. apart, and between every 4 rows a wider spacing of 30 in. is left. This 30-in. spacing is used by the harvesters, who, kneeling on burlap pads, cut the tops by hand, sort out the unwanted material, and pack the tops in wooden crates which are dragged along on small wire sleds (Pl. 55(*b*)). Each crate holds 12 to 15 lb. of tops when packed. The cutter works his way down the 30-in. spacing, cutting the 2 rows adjacent on either side. The tops are cut ½ to 1 in. above the soil line (Pl. 56(*a*)), and a further 1 to 2 in. is then cut from the bottom of the leaves. All flower-stalks are removed before placing the tops in the crate, and in April, when the plants are flowering freely, perhaps one-half of the harvested material must be discarded. Flowering lasts for about three cuttings in spring and summer, and decreases with later harvests. The size of the labour crew is so adjusted to the size of the field that harvesting is continuous—by the time the crew has worked across the field, the first part that was harvested is again ready to be cut.

To maintain high quality in the frozen product, the harvested tops are taken to the processing plant, where they are cooled, washed, cut into ⅛ in. pieces, and packaged and frozen as rapidly as possible. The product is inspected several times during processing; sanitary precautions similar to those in modern dairy practice are observed. The frozen product is loose and granular; it is packaged in small plastic cups for home use, and in several sizes of larger containers for commercial use. Dairies, which use chives with cottage cheese, are important commercial purchasers. Most of the output goes to large cities such as Los Angeles, San Francisco, New York, and Chicago.

LEEK, KURRAT, AND GREAT-HEADED GARLIC
(*Allium ampeloprasum*)

Leek and kurrat, along with the common onion and garlic, are among those vegetables whose culture and use can be traced back for three or possibly four thousand years to the early civilizations of the Near East. These early records do not always distinguish clearly between leek and kurrat (Täckholm & Drar, 1954), which is not surprising, as these two closely-related, non-bulbing forms are more distinct today in their use—leek for its false stem, kurrat for its green tops—than in their appearance (Chapter III).

Leek has spread from its original home—probably the eastern Mediterranean area—to the rest of the world. Helm (1956) gives evidence of its presence in Europe in the Middle Ages, and it was undoubtedly brought to America repeatedly by early settlers. Kurrat, on the other hand, has remained in the Near East, where it is cultivated mainly by Arab peoples. While in Egypt the leek is grown in limited areas around the large cities for local consumption and some export, kurrat is more widely grown. Täckholm & Drar state that kurrat is also cultivated to the north and east of Egypt, at Hebron in Jordan, and, in the southern part of the Arabian peninsula, near Mecca and in Yemen. At Davis, California, we have grown an introduction of *Allium ampeloprasum* from Afghanistan which is very similar to the kurrat of Egypt. The distribution of kurrat in the Near East is certainly not well known at the present time, partly because of its confusion with leek.

W. A. Warid and M. el Gammal inform us that an average of about 1,300 acres of kurrat was grown in Egypt each year during the 5 years 1956–60, and that the acreage has been slowly but steadily increasing. Yields have averaged about 15 tons of tops per acre per year. The kurrat is direct-seeded in the field, either during January and February or in September and October. The first cuttings of tops are taken after 3 to 4 months, with recuttings at intervals of 3 to 4 weeks during summer and of 4 to 6 weeks during winter. Täckholm & Drar (1954) state that a planting may be cut for 15 to 17 months before the yields decline. During the second year of growth, the farmers leave a few beds uncut for seed production. Kurrat is a popular vegetable for fresh consumption, and is also used as a seasoning in such foods as fried broad beans (*Vicia faba* L.).

Leeks are mainly a crop of northern Europe, and are of much less importance in the United States and Canada. In these latter countries they are usually supplied to large cities by market gardeners, and are consumed largely by immigrants who have known and used them elsewhere.

In Italy, leeks are of minor importance compared with onions and garlic, and no statistics are available of their production. In northern Italy, however, they are of value because they provide a green crop during the winter, when few other vegetables are available. The main areas of production are Piedmont, Lombardi, and around Venice. In central and southern Italy, leeks are limited to home gardens or to small areas of cultivation for local markets.

In Spain, most leeks are produced in the far north, in the provinces of Guipúzcoa, Vizcaya, and Logroño, where they are grown mostly without irrigation. Between 1957 and 1960, some 490 ha. were in leeks, with a production of something over 9,000 tonnes per year.

France probably leads the world in leek production; some 350,000 tonnes enter commercial channels, and trade sources estimate that between 800,000 and 900,000 tonnes are produced annually.

Leeks are important in northern European countries such as Belgium, Denmark, and the Netherlands. They are among the six most important vegetables in Belgium, and are raised largely around such cities as Ghent, Louvain, and Mons. Between 1952 and 1954, Denmark produced about 6,500 short tons (1 short ton = 0·907 tonne) per year, and the Netherlands' production was about twice that amount, one-fifth of the total being exported. Between 1950–51 and 1954–55, leek production in the United Kingdom averaged between 14,000 and 15,000 tons per year.

Few data on leek production are available for eastern Europe. In Poland, Professor Chroboczek estimates that leek production may amount to about 10 per cent of that of the bulb onion. Between 1948 and 1955, Czechoslovakia produced about 1,700 tonnes yearly on an average area of 180 ha. East Germany raised about 900 ha. of leeks each year between 1953 and 1956.

If one compares the cultivars of leek with those of the common onion, one is at once struck by the widespread cultivation of certain of the leek cultivars. While most onion cultivars perform satisfactorily in a limited area only, most leek cultivars will grow at least reasonably well wherever the crop is produced. The main reason for this great adaptability of the leek is that it neither forms bulbs nor enters a rest period, as does the common onion, but continues growth and can be harvested over a long period of time. The strong bulbing responses of the onion, and hence its rigid temperature and photoperiod requirements for proper maturing, are absent in the leek. The leek is also more adaptable because it has greater cold-resistance than the onion. Like the onion, however, the leek is induced to bolt by low winter temperatures; as bolting plants are not desirable for market, prolonged periods of low temperature markedly affect planting dates and production periods.

Leeks are always started from seed and need a fairly long growing-season to reach a marketable size. In cool climates, leeks are usually planted as early in the spring as possible, and are frequently transplanted from hotbeds or cold frames into the open as soon as the soil becomes warm. Such early plantings are often ready by late summer; successively later plantings may be harvested into the autumn, winter, and early spring. These later plantings are direct-seeded or grown from transplants. When the false stems are to be blanched, the leeks are transplanted into trenches, where the soil can be gradually banked against them. Leeks are sufficiently cold-resistant that even in cool climates harvesting can continue throughout the winter, when many other greens are off the market. Often the plants which were started in the autumn are bolting by late spring, and are no longer suitable for harvest. Because of bolting on one hand and of winter demand on the other, leek production is usually heaviest during the late autumn, winter, and early spring months, and is light or lacking through the summer. Unlike onions or garlic, leeks have no definite maturity dates and, as markets usually accept a wide range of sheath sizes, single plantings may be harvested over a considerable period.

Leek cultivars differ from one another mainly in such characteristics as length and diameter of the sheath part, leaf spacing, breadth and colour of the leaf-blades, and in vigour, ease of bolting, and resistance to cold. Vigorous types are best for summer production; resistance to cold is of special importance where leeks are to be harvested throughout the winter, while slowness to bolt permits a prolonged harvest period in the spring.

Winter hardiness is necessary in cultivars that are grown at high elevations or in the North. Thus, in northern Italy, either 'Lungo Invernale d'Italia' or 'Carentan' is preferred because of hardiness, while in southern Italy such cultivars as the less hardy 'Palermo' and 'Grosso Corto d'Estate' are grown because they may be more productive or of better quality. Where these cultivars are grown at different seasons, they may be referred to as either summer, autumn, or winter types. Huyskes (1959) notes that, for the Netherlands, no cultivars could be recommended for both autumn and winter culture. According to Helm (1956), the cultivars of southern Europe show a much stronger tendency to produce lateral branches or lateral buds than do those which are raised in the North. These southern types grade into forms which are known as perpetual leeks, and which branch profusely from the base, forming clusters of stems. At Davis, California, we have grown lines which produce many large, lateral cloves, i.e. which appear to be almost intermediate between the leek and the great-headed garlic.

Little additional information on the culture of the leek needs to be given here, because leek culture is in so many ways similar to the direct-seeded or transplant culture of the common onion. Pls. 57(*a*) and 57(*b*) show a commercial planting of leeks in California. The crop illustrated in Pl. 57(*a*) is 13 months from seeding, which indicates the length of time the crop may occupy the land, and also the long period over which a single planting may be harvested. The grower of the field shown in these photographs has for many years supplied local markets from November to May, when demand is greatest. These leeks are seeded mechanically in a nursery, usually between February and April, using 1 to 2 lb. of seed per acre. Two rows are planted per bed, using beds which are similar to those in the field shown in Pl. 57(*a*). After about 3 months the seedlings are dug, trimmed, and placed 4 in. apart in 2 furrows on the tops of beds which are spaced 36 in. apart. They are then covered by ploughing soil from the irrigation furrow between the beds, and are irrigated immediately. Sprinklers are not used, because the tall leek tops make them difficult to move.

Castronovo *et al.* (1955) have investigated spacing effects with leek and found, as Couto did with garlic (Chapter XVIII), that the size of individual plants increased with increases in spacing, while yield per unit area decreased. These workers planted leeks in single rows 40 cm. apart, and varied the spacing between plants in the rows from 5 to 20 cm. Each grower must work out the spacing that is best suited to the peculiarities of his own cultural practices, bearing in mind the effect of spacing on yield and plant size. *See also* Haworth (1961).

Leeks are subject to many of the diseases of onions; Walker (1952) lists pink-root, purple blotch, smudge, smut, white-rot, and downy mildew, among these. As with onions, thrips are probably the most serious insect pest and should be dealt with as on onions.

Leeks are more difficult to harvest than onions, because they are usually planted deeper, and because they have an extensive and matted root system at the time of harvest. In one method of harvesting, a tractor-drawn knife is run beneath the plants, 1 to 2 in. below the stem, and then the lateral roots are cut with a knife or a shovel. The soil is shaken off and the roots are later washed with water under pressure. Where a tractor is used to undercut the plants in the field, transplanting to a uniform depth is essential. The plants are usually bunched for market and may or may not be graded for size, depending on market demands.

Harvested leeks store well and, if properly crated, may be held for 1 to 3 months at 32°F. and 90 to 95 per cent relative humidity (Wright *et al.*, 1954).

Most of the leek seed produced in the United States is grown in California, although some comes from southwestern Idaho. For seed production, seed is usually sown in the spring and the seed crop is harvested the following year, somewhat later than that from the common onion. While most seed is produced from direct-seeded plantings using 2 to 3 lb. of seed per acre, the crop can be planted at a heavier rate and the seedlings transplanted in the autumn.

Seed-heads of leek are harvested by hand. As they are difficult to dry, they require a long period for field drying and sometimes must be dried artificially. Yields average about 500 lb. per acre.

When the seed crop is mature, the leek plant has usually produced several cloves, which will produce another seed crop in the following year. By 'volunteering' the crop in this way, seed may be harvested from one planting for a period of 4 to 6 years before the stand becomes so reduced as to decrease yields. A carefully planned weed-control programme is required if the same planting is to be harvested for several years.

The third cultivated form of *A. ampeloprasum*, the great-headed garlic, with its leek-like tops and flowers and its large garlic-like bulbs, is a curious plant. It appears to be well known in the Americas, in Europe, and in parts of Asia and Africa, but almost always as a home-garden plant rather than as a commercial crop.

We have grown at Davis many collections from home gardens in California, but have known of only two or three attempts by farmers to grow the plant commercially. Usually, when farmers have been interested in the crop, it has been for use as garlic. In our experience, it is much stronger in flavour than the common onion, but is considerably less pungent than garlic, and so it is hardly a substitute for either. We know of people who use great-headed garlic regularly in their home cooking, but it is quite uncommon in markets. As a substitute for garlic in dehydration, it lacks pungency and does not yield a white product.

Great-headed garlic is a vigorous plant and, if it were grown commercially, should yield well. Because of its very large cloves, however, a large part of the crop would have to be retained as planting stock. Some lines produce a few true seeds, but most are almost completely sterile.

JAPANESE BUNCHING ONION OR NEGI (*Allium fistulosum*)

During prehistoric times, when the common onion, garlic, and forms of *Allium ampeloprasum*, were being brought into cultivation by the early civilizations of the Near East, the agriculturists of China were domesticating quite different onions that were native to eastern Asia. Of these, the Japanese bunching onion (or Welsh onion, as it came to be called in Europe) was the most important. As with the common bulb onion of the West, many variants were selected and grown, and these were used in diverse ways to liven the starchy diets of these eastern peoples. Again, as with the common onion, the origin of the bunching onion is lost in history, and its wild parent or parents remain unknown (cf. Chapter III).

Kumazawa (1956) notes that white-stemmed varieties were described in Chinese books of 100 B.C. to A.D. 650, and that *Allium fistulosum* was mentioned in Japanese literature as early as A.D. 918, though of course under other names. He further suggests that most of the present-day Japanese cultivars were probably introduced into Japan from China.

Today the bunching onion is raised as a crop plant across much of Siberia, although not at all extensively west of the Urals (Vvedensky, 1946). It is an important crop in China, especially in the north-east, and also throughout Japan. In these areas of eastern Asia, *A. fistulosum* was historically *the* important onion, i.e. the main onion grown long before the bulb onion, *A. cepa*, was introduced.

The Japanese bunching onion was probably introduced into Europe by the end of the Middle Ages, or earlier, and into Russia from Europe (Helm, 1956). In Europe and America it is used mostly in home gardens as a green bunching onion, although some small commercial acreages are grown. *Allium fistulosum* has been crossed with *A. cepa* to produce the 'Beltsville Bunching' green onion and the 'Louisiana Evergreen' and 'Delta Giant' shallots (cf. pp. 46, 137).

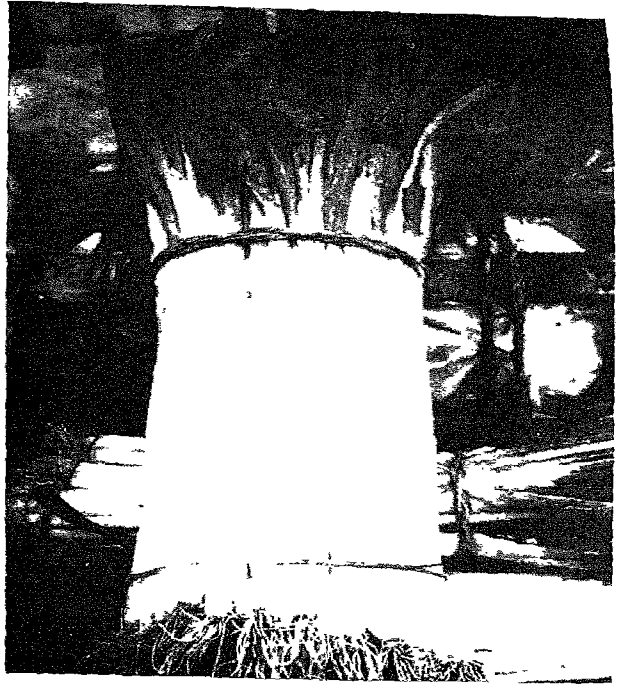
Between 1955 and 1960, Japan produced a yearly average of about 58,500 acres of *A. fistulosum*, which yielded each year about 342,000 tonnes, or slightly over 5·8 tonnes per acre.

Production is widely distributed over Japan but is greatest near Tokyo and central Japan. The leading prefectures, with their 1960 tonnages, were: Saitama, 45,400; Chiba, 45,000; Ibaragi, 23,400; and Kanagawa, 21,700. Other prefectures producing over 10,000 tonnes each were Shizuoka, Gunma, Nagano, Fukushima, Tochigi, and Tokyo. Exports of the bunching onion from Japan are very small, and are limited to the Ryukyu Islands.

Statistics of production of the Japanese bunching onion outside of Japan are scarce. According to Helm (1956) it is used to some extent in Europe, especially in the winter and early spring when fresh *A. cepa* is not available. Professor Chroboczek writes us that, although of minor importance in Poland, this onion is grown near large cities, such as Warsaw, for green bunch onions to be marketed in May and early June, when other greens are scarce. Although the Welsh onion has long been known in England, Stearn (1943) notes that it ceased to be a market-garden plant by the end of the nineteenth century, and has now almost passed out of cultivation. In India its use has been declining, and in some countries, such as Egypt, it is unknown.

Dr H. K. Pyo tells us that in Korea the common onion is now used in the restaurants of large towns, and by people who have learned to eat it in other countries. However, most of the native people eat the Japanese bunching onion, and the farmers prefer this species to *A. cepa*. In Japan and China, *A. cepa* is gradually replacing some of the older onion cultures that are based on *A. fistulosum*; but in many ways the uses of the two are distinct, so that they supplement rather than compete with each other.

(*a*) A planting of the Japanese bunching onion or negi, growing on the Saitama Experimental Station near Tokyo The soil has been banked up high around the plants, to produce the long white sheaths shown in Pl. 58(*b*).



Photos Mas Yamaguchi

(*b*) Blanched leaf sheaths (nebuka) of the Japanese bunching onion, *Allium fistulosum*, Tsukiji Market, Tokyo This bundle, 15 to 18 in. long, was harvested from a planting such as that shown in Pl. 58(*a*).

PLATE 58

In a discussion of vegetable production in Taiwan, Luh (1956) states that the Japanese bunching onion (referred to in his report as 'shallot') '. . . . is the only vegetable which produces a big crop all the year around. It is seen every day and everywhere on the market and is sold at low price.' Luh gives production statistics for the period 1945 to 1953. About 12,580 tonnes were grown on 1,850 ha. in 1945, and by 1953 this had increased to 22,185 tonnes on 2,827 ha. Professor Chang-Chih Hu writes us that in 1958 the production in Taiwan was 27,243 tonnes on 3,271 ha.

Allium fistulosum, grown from the cold regions of Siberia to the tropics of southern China and southeastern Asia, shows a remarkable range of adaptation to climate. Although it does not bulb, but grows continually by tillering throughout most of the warm season of the year, there is considerable morphological variation among the cultivars, and each of several quite distinct types of culture has forms that are best suited to it. Tender-leafed forms are raised for their edible tops, whereas long, thick sheaths characterize the kinds that are raised for their blanched leaf-bases. Again, some crops are used in the seedling stage, and finally there are kinds which are reproduced by top-sets and used much as we use small green onions. Cultivar suitability may also vary with climate; usually, cultivars that are adapted to northern areas lose their leaves during the winter, while those that do best in warm areas remain green throughout the year. Much of the information in the following account of onion culture in Japan was obtained from the book of Kumazawa (1956) and from correspondence with Professor Tadayoshi Sugiyama. The information on China was largely supplied by Dr Robert C. Tang.

The most elaborate and exacting culture of the Japanese bunching onion is that designed to produce long, blanched sheaths (Pls. 58(*a*) and 58(*b*)). A fertile soil is necessary, and much effort and time are required, as the crop is usually in the ground for most of a year, or longer, before harvest.

In cold climates the crop for sheaths is planted in the spring and harvested during the following winter. In Hokkaido the spring plantings are made in April and early May, and farther south the plantings are progressively earlier. In warmer areas (around Tokyo and in Kyushu), plantings are made in the autumn for harvest a year or more after planting. Transplants 30 to 35 cm. high are set 8 to 10 cm. apart, and soil is mounded around the plants to a depth of about 18 cm. The beds may be 70 cm. wide, or considerably wider in sandy soils. Because of deep planting, good drainage must be maintained, and thus the furrows between the beds are quite deep.

Many cultivars are used for the production of blanched leaf-bases. These tend to produce fewer tillers than the kinds which are grown for tops, and must be capable of producing long, thick sheaths. For example, 'Kaga', which loses its leaves during the winter, is grown in the colder regions of Japan; 'Senju', an intermediate type, in central Japan; and 'Kujyo', which is green throughout the winter, in southern Japan (Kyushu). When cultivars which lose their leaves in winter are grown in warm areas, the sheaths tend to be thin and of poor quality.

In connection with the sheath culture of *A. fistulosum*, we should mention the term *nebuka*. This term refers to the long, white sheaths produced by blanching (Pl. 58(*b*)). It may be used as a type name to include cultivars that are so used, and in seed catalogues may be attached to the cultivar names—e.g. 'Senju'-nebuka, to designate the purpose for which the cultivar is suited. It is not the name of a particular onion, and should not be used as a cultivar name.

Cultivars which are grown for their green, unblanched tops, such as Kujyo and Koshizu, may be harvested after only 3 or 4 months, and seldom remain in the ground as long as the blanched-sheath crop. The main centre of culture for green tops is in the Osaka-Kyoto area, but some are grown also as far south as Kyushu. As the green tops must be used when fresh, they are shipped less frequently within Japan than are the blanched sheaths. The crop may be direct-seeded or transplanted. Unlike the sheath-onions, it is mainly a summer crop and may be interplanted with other crops. Onions that are grown for tops are commonly planted in several rows on wide beds which are separated by shallow furrows.

The top-set cultivars of *A. fistulosum* are of small stature and are used mainly by home gardeners to produce green onions. Propagation is by the top-sets and, like the other cultivars whose tops die down in winter, they are suited to cool climates in the North.

The bunching onion is also used in the seedling stage in special Japanese dishes. The plants are harvested and sold in bunches when they are only 3 to 4 in. high. These are grown mainly in northern Kyushu.

Allium fistulosum culture on the mainland of eastern Asia appears to resemble in many ways that of Japan. In northern China and Manchuria the crop is grown largely for winter use and the stalks are covered with soil for blanching. Some cultivars are adapted to both sheath and leaf production. In central China, and especially farther south, the unblanched tops are used and, as in the warmer areas of Japan, cultivars are grown which keep their green tops throughout the year.

As in Japan, the production of blanched sheaths is laborious and requires good soils and heavy fertilization. Space is conserved by transplanting twice after seeding. When the seedlings are about 7 in. high, they are set in bunches of 2 to 3 at spacings of about 4 by 4 in. They are fertilized with night soil about every 10 days, and after about 60 days are set in furrows that are about 6 in. wide and some 6 to 12 in. deep. The plants are placed 1 to 3 in. apart in the furrow, and the soil is worked upwards gradually until about 12 in. of the sheath is covered. The rows are about 3 ft apart. At harvest, the soil is pulled away from the sheath and the latter is cut about 1 in. above its base. Soil is then pushed back gradually as the plants grow, and a second crop is produced. Yields of the two crops total from 10,000 to 25,000 lb. per acre. For this culture a large type of bunching onion which does not tiller extensively is used. If used as a green onion, this type is transplanted into level fields and set in bunches of 2 to 3 at approximately 8 by 8 in. spacings.

For the green crop, a smaller type of plant with sheaths about $\frac{1}{4}$ in. in diameter is usually grown. This plant tillers to produce perhaps 20 stalks from one seedling during a season's growth. The plants are started on seed-beds and transplanted to shallow furrows about 15 in. apart. Groups of 2 or 3 plants are set 3 to 5 in. apart in the row. Yields average about 15,000 lb. per acre.

In Japan, breeding of *A. fistulosum* has not been extensive. Farmers commonly produce seed for their own use—frequently by leaving part of their market field unharvested. Fields which are grown specifically for seed production are usually planted in June or July. Kumazawa (1956) states that there seems to be little crossing among cultivars and, considering the methods of seed production, the cultivars have shown surprisingly little change with time.

In the United States, in southwestern Idaho, seed is produced by planting 3 to 5 lb. of seed per acre in May or June. The crop is not transplanted and produces seed in the second year, somewhat earlier than does the common onion. Harvesting operations are similar to those for the common onion. Most cultivars are good seeders, commonly yielding 1,000 or more lb. of seed per acre.

As with most *Allium* crops, thrips appear to be the most important insect pest. Kumazawa (1956) states that, in Japan, thrips attacks may be reduced by growing summer onions in areas of high humidity. Among the diseases, purple blotch, downy mildew, and rust, appear to be the most important in Japan. Professor T. Sugiyama writes us that a virus, possibly yellow dwarf, has become important in some districts, especially in the Saitama Prefecture. The Japanese bunching onion appears not to suffer from either smut or smudge.

Rakkyo or Ch'iao T'ou (*Allium chinense*)

Rakkyo is primarily a vegetable of China, Japan, and the countries of southeastern Asia. When found elsewhere in the world, as in the Western Hemisphere, it is grown and used almost exclusively by East Asian migrants. Professor Saburo Kumazawa, Director of the National Kyushu Agricultural Experiment Station, informs us that rakkyo is said to have been used as a drug in China as long ago as 3,000 years. Nowadays, in China, it is eaten fried with a little oil, as vinegar pickles (with or without sugar or honey), or as brine pickles. In Taiwan, all rakkyo is used after being boiled. In southern Asia, brined rakkyo is reprocessed with vinegar and eaten in curries. In Japan it is consumed as pickles only. This information, and most of that which follows, is drawn from a paper by Mann & Stearn (1960), who point out that in most of the pertinent literature rakkyo is referred to by the binominal *Allium bakeri* Rgl., a name which is now considered to be a synonym of the earlier name, *A. chinense* G.Don.

Rakkyo is grown extensively in Japan, in the provinces of central and southern China, less commonly in the South Sea Islands, and only occasionally in northern China and Manchuria. The rakkyo that is grown in southern China is pickled and shipped to the South Sea Islands from Amoy and Swato. Pickles are also shipped from the ports of Saigon and Singapore.

Production figures for China are not available, but Japan is reported to have grown 11,000 acres of rakkyo in 1942. Over half of the rakkyo in Japan is grown for household processing; the rakkyo that is grown for commerce is produced largely in Fukui, Toyama, Kayoshima, Chiba, and Ibaragi Prefectures. Most of this is used for canning, but that which is grown at Kagoshima in the South is harvested in early April and May for fresh markets.

In California and Hawaii, where most of the Chinese and Japanese in the United States reside, a small acreage (perhaps 2 to 4 in California, less in Hawaii) is grown commercially for the fresh market.

Rakkyo is almost always consumed as pickles and, as shown in Table XXXI, these are exported from Japan to many parts of the world. The pickled onions which are exported from Japan are exclusively of this species (not *A. cepa*), and most of the rakkyo that is consumed outside of eastern Asia is probably from Asian exports rather than from local plantings.

As was indicated in Chapter IV, rakkyo is unusual among the Alliums in that it flowers in the autumn after a period of summer dormancy. The flowers do not set seed, however, and the plants are propagated by bulb

TABLE XXXI

EXPORTS OF RAKKYO FROM JAPAN, 1957

(Mann & Stearn, 1960)

Destination	Barrels	Per Barrel	Short Tons
U.S.A. (including Hawaii)	13,548	26 lb.	176·0
Canada	506	26 lb.	5·5
Peru	102	26 lb.	1·6
Mexico	40	26 lb.	0·5
Okinawa	3,067	11·3 kg.	38·1
Singapore	7,102	110 lb.	390·6
Malay	3,041	110 lb.	167·2
Hong Kong	794	110 lb.	43·7
Guam Island	511	26 lb.	6·6
South Sea Islands	78	26 lb.	1·0
Borneo	50	110 lb.	2·8

divisions. Bulbs are usually planted 8 cm. apart in rows 60 cm. apart or, as much rakkyo is raised for home or local consumption, the bulbs may be planted in or around other crops. Light sandy soils facilitate harvesting and are believed to favour the formation of the small bulbs which are preferred for pickling. On these light soils, rakkyo may respond well to heavy fertilization.

In Japan the bulbs are usually planted between August and September and make their growth during the winter and spring. The leaves wither in early summer, and the crop is usually harvested during the dormant period between May and August. By this time, each planted bulb will have given rise to a cluster of a few to perhaps a dozen or more bulbs which are held together by a common stem at their base. The preferred-quality pickles are made from small bulbs, and in the Fukui and Toyama Prefectures, where the crop is grown almost entirely for canning, rakkyo may be harvested after two years of growth in order to obtain large numbers of small bulbs. Here rakkyo is grown on cheap dune land and needs little care during the summer dormant period.

The average yield in Japan as indicated by the 1942 census was 2,907 kg. per acre (3·2 short tons per acre). The average yield in Okinawa is nearly 5 short tons per acre, and under the best conditions in southern Japan, yields of 5 to 8 tons per acre can be expected; but in the north the yields would be lower.

The three commonest cultivars in Japan are Yatsubusa (many small bulbs with narrow necks, but of inferior quality and poor yield), Rakuda (few large bulbs, good yield), and Tama-Rakkyo (many small bulbs of good texture, good yield). The last cultivar, an introduction from Taiwan, is replacing the older cultivars—especially because its small bulbs make unnecessary the two-year culture that is sometimes practised with the older cultivars.

The bulk of rakkyo is consumed as pickles (rakkyo zuke), either made at home or processed commercially. These may be sweet pickles preserved in vinegar and sugar, or sour pickles preserved in vinegar and salt. There are many variations in the pickling process, but the bulbs are usually first steeped for several days in brine and then transferred either to vinegar, sake, and sugar, or to vinegar and salt. A few small red peppers are usually added, and the commercial product may be heat-sterilized after canning. Soy sauce may be added to give an amber-coloured product called bekko-zuke (tortoise-shell-coloured pickles). The highest-quality small bulbs are known as hana-rakkyo (flowering-rakkyo). Japan ships most of its rakkyo zuke in wooden barrels, from which it is bottled locally for retail sale.

The small acreage observed in California (p. 242) is grown for the fresh market in San Francisco. Here the usual practice for irrigated row crops is followed: one or two bulbs are planted every 8 or 9 in. in the row, and two rows about 12 in. apart occupy the top of a raised bed.

The beds, separated by an irrigation furrow, are about 40 in. apart. Bulbs are planted in April, and in August the soil is banked 3 to 4 in. deep around the plant tops, so that, when the crop is harvested in December or January, there will be several inches of white 'stem' above the bulb. The blanching process is similar to that followed for the fresh market produce in Japan.

CHINESE CHIVES OR NIRA (*Allium tuberosum*)

As noted in Chapter III, Chinese chives range over much of eastern Asia, from Mongolia to Japan and the Philippines, and westwards through Thailand to northern India. Along with the Japanese bunching onion and rakkyo, this onion has long been used for food by the peoples of eastern Asia. Its name in Mandarin is *kiu ts'ai*—a name which, according to Stearn (1946*a*), goes back at least to the Han period (*ca.* 206 B.C. to A.D. 220). In Japan it is called *nira*, and is believed to have been an early introduction from China. Professor T. Sugiyama informs us that there are records of its culture in Japan as early as A.D. 928. Other evidence that *A. tuberosum* was probably first used by the Chinese and spread from China to much of its present range is suggested by the fact that its names in the Philippines, Java, and Malaya, are evident corruptions of *kiu ts'ai*. Its hardiness, and the fact noted by Stearn (1946*a*) that it does not flower freely in the tropics, but must be raised from imported seed, suggest that it is not a native of warm areas.

According to Dr Robert C. Tang, the culture of Chinese chives is more important in northern and central China than in southern China. In China this *Allium* is direct-seeded in light, loamy soil in furrows some 4 to 6 in. deep. As the plants grow, the furrow is filled with soil, and when the plants are about 4 in. high, straw mats about 18 in. wide are leaned from both sides of the row to form a roof over the plants and exclude the light. After 3 to 4 weeks, when the plants are sufficiently blanched, the mats and soil are removed, and the tops are cut off about 1 in. above the rhizome. As the tops of the plants grow out again, the soil is moved back and the blanching process is repeated. A single planting may be used for 4 or 5 years, much as we use an asparagus planting.

The green, unblanched leaves of Chinese chives are also eaten, and in the early autumn the tender flower-stalks, which are just emerging, are cut and used along with the leaves. In the appropriate season, small bundles of these leaves and flower-stems are common in the Chinese groceries in San Francisco. Their flavour is strong, quite like that of garlic, and they are used in small quantities to season meat dishes.

Although Chinese chives or nira is not a major vegetable in Japan, it is widely grown. In 1958 approximately 5,189 tans (1 tan = *ca.* $\frac{1}{4}$ acre) of nira were raised, yielding about 5,400 tonnes. The Tohoku district of northern Honshu, and the Prefectures of Chiba and Okayama, are centres of nira production, the Chiba Prefecture supplying most of the nira for the important Tokyo market. Unloads on the Tokyo market for 1958, 1959, and 1960, were 1,318, 1,692, and 1,905 tonnes, respectively. Both green and blanched leaves are used in Japan, and each planting is cut several times during the year.

The Chinese chive is one of the important vegetables that are produced in Taiwan. Data from Luh (1956) indicate that the area in *A. tuberosum* increased from 1,123 ha. in 1945 to 1,800 ha. in 1953, while yearly production increased from 9,360 to 14,000 tonnes. According to a letter from Professor Chang-Chih Hu, 2,230 ha. were in Chinese chives in 1958 and 17,654 tonnes were produced. This crop is harvested throughout the year and yields well during July and September, the season when few other fresh vegetables are being marketed. It is interesting to note that Professor J. H. MacGillivray, working on vegetable transportation in Taiwan in 1957, included Chinese chives in his transit studies because the harvested leaves, like our asparagus, have a high rate of respiration and heat quickly unless well ventilated or artificially cooled. Even when in transit for less than 24 hours, Chinese chives benefited from pre-cooling or packaging with ice.

At Davis, California, we have grown two lines of Chinese chives, from Japan, which differ slightly in leaf width. The broad-leafed form is known as *onira*, the narrow-leafed form as *konira*. Although the konira blooms somewhat later than the onira, there are no striking differences and, in general, this species shows little variation. Over a period of years, *A. tuberosum* has always flowered freely at Davis, and the fragrant flowers, which attract a great variety of insects, produce an abundance of seed.

APPENDIX I

CHEMICAL NAMES OF PESTICIDES MENTIONED IN CHAPTERS XVI AND XVIII

Name	*Type of Name*	*Chemical Name*
ALDRIN	Common	1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4-*endo-exo*-5,8-dimethanonaphthalene
CHLORDANE	Common	1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methanoindane
DDT	Common	1,1,1-trichloro-2,2-bis (*p*-chlorophenyl) ethane
DIELDRIN	Common	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, exo-4,8-dimethanonaphthalene
ETHION	Common	o,o,o′-tetraethyl S,S8-methylene bis-phosphorodithioate
HEPTACHLOR	Common	3a,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindane
KELTHANE	Proprietary	1,1-bis(chlorophenyl)-2,2,2-trichloroethanol
LINDANE	Common	gamma isomer of 1,2,3,4,5,6-hexachlorocyclohexane
MALATHION	Common	o-o-dimethyl dithiophosphate of diethyl mercaptosuccinate
PARATHION	Common	o,o-diethyl o-p-nitrophenyl phosphorothioate
TELONE	Proprietary	dichloropropanes
TOXAPHENE	Common	chlorinated camphene (containing 67·0 to 69·0 per cent of chlorine)
TRITHION	Proprietary	*o,o*-diethyl *S*-*p*-chlorophenylthiomethyl phosphorodithioate
VC-13	Proprietary	*o*-2,4-dichlorophenyl *o,o*-diethylphosphorothioate

APPENDIX II

CONVERSION FACTORS OF WEIGHTS AND MEASURES

MEASURES OF WEIGHT—*Avoirdupois to Metric*

1 dram (dr.)	27·343 grains	1·772 grams
1 ounce (oz.)	16 drams	28·3 grams
1 pound (lb.)	16 ounces	0·454 kilogram
1 stone (st.)	14 pounds	6·350 kilograms
1 quarter (qr.)	2 stones	12·701 kilograms
1 hundredweight (cwt.)	4 quarters	50·802 kilograms
1 (long) ton	20 hundredweight	1·106 tonnes

Metric to Avoirdupois

1 milligram (mg.)		0·015 grain
1 gram (gramme, gm.)	15.432 grains	0·564 dram
1 kilogram (kg.)	1,000 grams	2·205 pounds
1 tonne	1,000 kilograms	0·984 (short) ton

American Weights to Metric

1 pound		453·592 grams
1 cental	100 pounds	45·359 kilograms
1 (short) ton	20 centals	0·907 tonne

Metric to American Weights

100 kilograms (kg.)	1 quintal (q.)	2·205 centals (220·5lb.)
1 tonne	1,000 kilograms	1·102 (short) tons

MEASURES OF LENGTH—*British to Metric*

1 inch (in.)		25·400 millimetres
1 foot (ft)	12 inches	30·480 centimetres
1 yard (yd)	3 feet	0·914 metre
1 mile	1,760 yards	1·609 kilometres

Metric to British

1 micron (μ)	1/1,000 mm. (1/1,000,000 m.)	1/25,400 inch
1 millimetre (mm.)		0·039 inch
1 centimetre (cm.)	10 mm.	0·394 inch
1 decimetre (dm.)	10 cm.	3·937 inches
1 metre (m.)	10 dm.	1·094 yards 3·281 feet 39·370 inches
1 kilometre (km.)	1,000 m.	0·621 mile

MEASURES OF AREA (*Based on 1 metre = 39·370 inches*)

British to Metric

1 square inch (sq. in.)		6·452 sq. centimetres
1 square foot (sq. ft)	144 sq. in.	0·093 sq. metre
1 square yard (sq. yd)	9 sq. ft	0·836 sq. metre
1 acre	4,840 sq. yds	0·405 hectare
1 square mile	640 acres	2·590 sq. kilometres 258·998 hectares

Metric to British

1 square millimetre (sq. mm.)		0·00155 sq. inch
1 square centimetre (sq. cm.)	100 sq. mm.	0·155 sq. inch
1 square metre (sq. m.)	100 sq. dm.	1·196 sq. yards
1 hectare (ha.)	10,000 sq. m.	2·471 acres
1 square kilometre (sq. km.)	100 ha.	0·386 sq. mile

MEASURES OF VOLUME—*British to Metric*

1 cubic inch (cu. in.)		16·387 cu. centimetres
1 cubic foot (cu. ft)	1,728 cu. in.	28·317 cu. decimetres
1 cubic yard (cu. yd)	27 cu. ft	0·765 cu. metre

Metric to British

1 cubic centimetre (cc. = ml.)		0·061 cu. inch
1 cubic decimetre (cu. dm.)	1,000 cu. cm.	0·035 cu. foot
1 cubic metre (cu. m.)	1,000 cu. dm.	1·308 cu. yards

MEASURES OF CAPACITY—(*based on 1 Imperial gallon* 4·546 *litres*)

1 American gallon—3·785 litres
1 litre—1,000 cc.

British to Metric

1 pint (pt.)—0·568 litre
1 quart (qt.)—2 pints—1·13 litres
1 gallon (gal.)—4 quarts—4·546 litres
1 bushel (bus.)—8 gallons—36·28 litres

Metric to British

1 millilitre (ml. = cc.)—0·061 cu. in.
1 centilitre (cl.)—10 ml.—0·610 cu. in.
1 litre (l.)—100 cl.—1·760 pints

TEMPERATURE

0° Centigrade (= Celsius) = 32° Fahrenheit

The following formulae connect the two major thermometric scales:

Fahrenheit to Centigrade: $^{\circ}\mathrm{C.} = 5/9\ (^{\circ}\mathrm{F.} - 32)$
Centigrade to Fahrenheit: $^{\circ}\mathrm{F.} = (9/5\,^{\circ}\mathrm{C.}) + 32$

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